FEATURES OF LEFT VENTRICULAR REMODELING IN TRAINED INDIVIDUALS DEPENDING ON THE ORIENTATION OF THE TRAINING PROCESS

Burdina V.R.[1]*, Danylchenko S.I.*[1]*, Golovchenko I.V.*[1]*, Morozenko D.V.*[2]*,*
Shevchenko A.S.[3, 4]*, Cherkova N.V.*[5]*, Dushik L.N.*[5]

[1]**Kherson State University, Kherson–Ivano-Frankivsk, Ukraine**
[2]**State Institution "Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine", Kharkiv, Ukraine**
[3]**Kharkiv National Medical University, Kharkiv, Ukraine**
[4]**Kharkiv Regional Institute of Public Health Services, Kharkiv, Ukraine**
[5]**V.N. Karazin Kharkiv National University, Kharkiv, Ukraine**

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ABSTRACT

Background. The study of left ventricular remodeling features in athletes depending on the orientation of the training process is relevant for optimizing training loads and preventing cardiovascular system disorders.

Aim. To identify the features of left ventricular remodeling in trained individuals depending on the orientation of the training process based on the analysis of morphometric parameters.

Materials and Methods. The study included 149 athletes aged 18 to 34 years specializing in various athletics disciplines. Depending on the training orientation, they were divided into three groups: speed-oriented (n=62), speed-strength oriented (n=49), and endurance-oriented (n=38). Echocardiography was performed with measurement of cardiac dimensions and left ventricular mass by Devereux formula. Statistical analysis was performed using SPSS 29.0 (IBM, USA). One-way ANOVA with Tukey HSD post-hoc test was used for intergroup comparisons. Two-way ANOVA was applied to assess the effects of training orientation and sex. The investigation was conducted as a private initiative of the authors, without grant funding.

Research Ethics. The study was conducted in accordance with the ethical standards of the World Medical Association's Declaration of Helsinki (1964–2024) with informed consent of all participants.

Results. Endurance athletes showed increased left ventricular end-diastolic dimension ($p<0.05$) and left ventricular myocardial mass ($p<0.01$) with proportional wall thickening (eccentric hypertrophy). Speed athletes had only systolic posterior wall thickening ($p<0.05$). Speed-strength athletes showed increased aortic diameter and left atrium size; two-way ANOVA confirmed independent training orientation effect after controlling for sex ($p<[0.05–0.01]$). Left ventricular mass strongly correlated with anthropometric parameters (height $r=0.72$, weight $r=0.74$, body surface area $r=0.76$) and left ventricular dimensions (end-diastolic dimension $r=0.74$, end-systolic dimension $r=0.81$). All parameters remained within physiological norms (wall thickness <12 mm, left ventricular end-diastolic dimension <60 mm).

Conclusions. The orientation of the training process is a determining factor in the formation of a specific "athlete's heart" phenotype. The obtained data justify the need for mandatory indexing of left ventricular myocardial mass to body surface area for correct intergroup and intersex comparative assessment.

Keywords: *physical therapy and rehabilitation, athlete's heart, echocardiography, exercise-induced cardiomegaly, morphometric parameters, speckle tracking echocardiography.*

Abbreviations

AC – Aortic diameter at the level of the valve Cusps
AO – AOrtic fibrous ring diameter
BSA – Body Surface Area
CVS – CardioVascular System
E/A – ratio of early (E) to late (A) ventricular filling velocities (as a parameter of transmitral blood flow)
EDD – End-Diastolic Dimension
ESD – End-Systolic Dimension
EchoCG – EchoCardioGraphy
IVS – InterVentricular Septum thickness
IVSd – InterVentricular Septum thickness in diastole

Corresponding Author:
Shevchenko Alexander S. – MD, MM,E&P, Director of the Kharkiv Regional Institute of Public Health Services, Ukraine.
🖂 8, Rymarska str., Kharkiv, 61057, Ukraine.
E-mail: as.shevchenko@knmu.edu.ua

IVSs – InterVentricular Septum thickness in systole
LA – Left Atrium anteroposterior dimension
LV – Left Ventricle
LVEDD – Left Ventricular End-Diastolic Dimension
LVESD – Left Ventricular End-Systolic Dimension
LVH – Left Ventricular Hypertrophy
LVPW – Left Ventricular Posterior Wall thickness
LVPWd – Left Ventricular Posterior Wall thickness in diastole
LVPWs – Left Ventricular Posterior Wall thickness in systole
LVMM – Left Ventricular Myocardial Mass
LVM – Left Ventricular myocardial Mass
LVMI – Left Ventricular Mass Index
MVD – Mitral Valve orifice size in Diastole
MVS – Mitral Valve orifice size in Systole
RV – Right Ventricle anteroposterior dimension

Introduction

Modern elite sports are characterized by a continuous increase in the volume and intensity of physical loads, which places high demands on the adaptive reserves of the athlete's body. The cardiovascular system undergoes the most pronounced morphofunctional changes, which in the literature are commonly defined as "athlete's heart" [1; 2]. A harmonious combination of cavity dilation and moderate myocardial hypertrophy ensures high cardiac performance; however, intensification of the training process without considering individual adaptation features can lead to failure of compensatory mechanisms and the development of pre-pathological conditions [3; 4]. This issue is particularly relevant because left ventricular hypertrophy, along with hypertrophic cardiomyopathy, is one of the leading causes of sudden cardiac death among athletes under 35 years of age [5; 6].

A key aspect of cardiac adaptation to physical loads is remodeling – structural and geometric reorganization that ensures the correspondence of the morphological substrate to functional demands [7; 8]. Left ventricular remodeling in athletes occurs in two main types – eccentric and concentric hypertrophy, which are formed primarily under the influence of dynamic or static loads, respectively [9; 10]. At the same time, prolonged overload can cause pathological transformation of the heart, limiting physical performance and posing a threat to the athlete's health [4; 11].

Despite a significant number of studies covering the phenomenon of "athlete's heart", questions of differential diagnosis between physiological and pathological LVH remain open [12; 13]. Establishing quantitative criteria for assessing morphometric parameters of the LV depending on the orientation of the training process is of particular practical importance, as it allows optimizing athlete preparation and minimizing the risk of cardiac complications. Athletics, as a sport encompassing a wide range of physical loads – from sprinting to distance running – is an optimal model for studying the influence of muscle activity specificity on cardiac morphometric parameters [14; 15].

This article presents the main echocardiographic findings, analyzes the identified structural changes in the context of the "gray zone" between physiological and pathological hypertrophy, and discusses their clinical significance for the long-term health of athletes.

The **aim** of the study was to identify the features of left ventricular remodeling in trained individuals depending on the orientation of the training process based on the analysis of morphometric parameters.

Materials and Methods

The study included 149 athletes aged 18 to 34 years, specializing in various types of athletics. Inclusion criteria comprised sports qualification not lower than 3rd category, regular training experience of at least 3 years, and absence of acute or chronic cardiovascular diseases in history. Exclusion criteria: presence of cardiac pathology; interruptions in the training process of more than 2 months during the past year; use of medications affecting hemodynamics.

Depending on the orientation of the training process, athletes were divided into three groups:

Group 1 – speed orientation (100 m, 200 m, 400 m, hurdle running);

Group 2 – speed-strength orientation (long jump, high jump, triple jump, pole vault; javelin, discus, hammer throwing; shot put);

Group 3 – predominant endurance development (800 m, 1,500 m, 3,000 m steeplechase, 5,000 m, 10,000 m; race walking 20 km and 50 km).

The distribution of athletes by groups depending on the orientation of the training process, sports qualification, and sex is presented in *Table 1*.

Among the examined individuals, 88 (59.1%) had high sports qualification (candidates for master of sports, masters of sports, international masters of sports), 61 (40.9%) – medium (3–1 sports

Table 1. Distribution of examined athletes depending on the orientation of the training process, sports qualification, and sex

Group	Sex	Highly qualified athletes	Rank athletes	Total
1	Male	16	14	30
	Female	18	14	32
	Total	34	28	62
2	Male	20	7	27
	Female	15	7	22
	Total	35	14	49
3	Male	9	9	18
	Female	10	10	20
	Total	19	19	38
Total		88	61	149

categories). Distribution of highly qualified athletes by sports titles: candidates for master of sports – 46, masters of sports – 31, international masters of sports – 11.

The study design involved a single examination of athletes during the preparatory period of the training cycle. Anthropometric measurements were performed using a unified methodology in the morning on an empty stomach: body length was measured using a vertical stadiometer with an accuracy of 0.5 cm, body weight – on electronic scales with an accuracy of 0.1 kg. Body surface area was calculated using a standard formula.

Echocardiographic examination was performed using an ultrasound scanner "MyLab 50" (Esaote SpA, Genoa, Italy) with a phased array probe at 2.5 MHz. Measurements were performed from the parasternal long-axis view in M-mode according to the recommendations of the American Society of Echocardiography. The following parameters were determined: interventricular septum thickness in diastole and systole, left ventricular posterior wall thickness in diastole and systole, end-diastolic and end-systolic dimensions of the left ventricle.

To assess measurement reproducibility, 10 random echocardiographic recordings were re-analyzed by two independent researchers. The intraclass Correlation Coefficient (ICC) for key parameters (LVEDD, LVPW) was >0.9, indicating high inter-rater agreement.

Left ventricular myocardial mass was calculated using the formula of Devereux R.B.:

$$LVM = 0.8 \times \{1.04 \times [(EDD + IVS + LVPW)^3 - (EDD)^3]\} + 0.6 \qquad (1),$$

where LVM – Left Ventricular myocardial Mass (g);

1.04 – myocardial density (g/cm^3);

EDD – left ventricular End-Diastolic Dimension (cm);

IVS – InterVentricular Septum thickness in diastole (cm);

LVPW – Left Ventricular Posterior Wall thickness in diastole (cm);

0.8 and 0.6 – correction coefficients.

Left ventricular mass index was calculated as the ratio of LVM to body surface area:

$$LVMI = LVM / BSA \qquad (2),$$

where LVMI – Left Ventricular Mass Index (g/m^2);

BSA – Body Surface Area (m^2).

To assess diastolic function, pulsed-wave Doppler of transmitral flow was performed to measure the early (E) and late (A) diastolic filling velocities and calculate the E/A ratio.

Additionally, the diameter of the aortic fibrous ring, aortic diameter at the valve level, and anteroposterior dimensions of the left atrium and right ventricle were measured.

Study Limitations

This study has several limitations. First, its cross-sectional design captures cardiac morphology at a single point in time, preventing assessment of the reversibility of the observed changes. Second, while M-mode and 2D echocardiography are standard methods, the absence of more advanced techniques like 3D echocardiography or Speckle Tracking Echocardiography (strain analysis) limits the comprehensive assessment of myocardial function. Third, potential confounding factors such as the use of nutritional supplements or ergogenic aids, which could influence myocardial remodeling, were not accounted for. Finally, the lack of a sedentary control group means that the baseline level of remodeling compared to the general population can only be inferred from literature data.

Statistical analysis was performed using SPSS 29.0 (IBM, USA). For each sample, the Mean (M) and Standard Deviation (SD) were calculated. Normality of distribution was assessed using the Shapiro–Wilk test. To compare the three groups based on training orientation, one-way ANOVA was used. For post-hoc pairwise comparisons, Tukey's HSD (Honestly Significant Difference) test was applied. Two-way ANOVA was applied to assess the effects of training orientation and sex. To assess effect size, Cohen's d was calculated. For effect sizes, 95% confidence intervals (95% CI) were determined. Correlation analysis was performed with calculation of the Pearson correlation coefficient (r). Differences were considered statistically significant at $p<0.05$.

Research Ethics

The study was conducted in accordance with the main bioethical principles of the World Medical Association Declaration of Helsinki (1964–2024). All participants were informed about the purpose and procedures of the study and provided written informed consent.

The study protocol was approved by the local Ethics Committee of Kharkiv Regional Institute of Public Health Services (Protocol No.6 dated September 11, 2024).

Results

Comparative analysis of cardiac morphometric parameters revealed significant differences depending on the orientation of the training process (*Table 2*).

Table 2. Morphometric parameters of athletes' hearts depending on the orientation of the training process (M±SD)

Parameter	Group 1 (Speed) n=62	Group 2 (Speed-strength) n=49	Group 3 (Endurance) n=38	p-value (ANOVA)	Post-hoc (Tukey HSD)
AO, mm	28.02±3.24	28.68±4.12	29.32±3.28	<0.05	G3>G1*
AC, mm	20.38±2.42	20.98±2.52	21.82±3.72	<0.05	G3>G1*
LA, mm	23.62±2.62	25.88±3.68	26.18±2.92	<0.01	G2>G1, G3>G1
RV, mm	15.62±3.42	16.38±3.48	17.12±3.58	<0.05	G3>G1*
IVSd, mm	7.78±0.88	8.08±1.06	8.14±0.74	<0.05	G3>G1*
IVSs, mm	10.38±1.38	10.84±1.52	10.98±1.22	<0.05	G3>G1*
LVPWd, mm	8.16±0.92	8.68±1.12	8.48±0.78	<0.05	G2>G1*
LVPWs, mm	14.24±1.72	14.90±1.62	15.04±1.52	>0.05	–
LVEDD, mm	47.24±4.42	48.02±5.22	48.62±4.58	<0.05	G3>G1*
LVESD, mm	31.32±3.72	31.92±4.38	32.14±3.48	>0.05	–
LVMM, g	164.82±36.82	180.62±56.12	187.82±39.92	<0.01	G2>G1*, G3>G1**
LVMI, g/m²	83.8±7.2	91.8±8.3	93.1±8.0	<0.01	G2>G1, G3>G1

Notes: * – $p<0.05$; ** – $p<0.01$; Post-hoc comparisons – Tukey Honestly Significant Difference (HSD) test;
G1 – speed-oriented; G2 – speed-strength oriented; G3 – endurance-oriented;
AO – AOrtic fibrous ring diameter; AC – Aortic diameter at the level of the valve Cusps;
LA – Left Atrium anteroposterior dimension; RV – Right Ventricle anteroposterior dimension;
MVD – Mitral Valve orifice size in Diastole; MVS – Mitral Valve orifice size in Systole;
IVSd – Interventricular Septum thickness in diastole; IVSs – Interventricular Septum thickness in systole;
LVPWd – Left Ventricular Posterior Wall thickness in diastole;
LVPWs – Left Ventricular Posterior Wall thickness in systole;
LVEDD – Left Ventricular End-Diastolic Dimension;
LVESD – Left Ventricular End-Systolic Dimension; LVMM – Left Ventricular Myocardial Mass.

Athletes in Group 1 (speed-oriented) showed the least pronounced cardiac adaptation, with the smallest absolute values for most parameters. No significant differences were found between groups for LVPWs and LVESD ($p>0.05$).

Athletes in Group 2 (speed-strength oriented) exhibited an intermediate phenotype, characterized by significantly greater LVPWd ([8.68±1.12] mm vs. [8.16±0.92] mm in Group 1, $p<0.05$) and LA size ([25.88±3.68] mm vs. [23.62±2.62] mm in Group 1, $p<0.01$). LVMM and LVMI in Group 2 were also significantly higher than in Group 1 ([180.62±56.12] g vs. [164.82±36.82] g, $p<0.05$; [91.8±8.3] g/m² vs. [83.8±7.2] g/m², $p<0.01$, respectively), but did not differ significantly from Group 3.

Athletes in Group 3 (endurance-oriented) demonstrated the most pronounced adaptive changes, with significantly larger LVEDD ([48.62±±4.58] mm vs. [47.24±4.42] mm in Group 1, $p<0.05$), LVMM ([187.82±39.92] g vs. [164.82±±36.82] g in Group 1, $p<0.01$), and LVMI ([93.1±±8.0] g/m² vs. [83.8±7.2] g/m² in Group 1, $p<0.01$). They also showed increased dimensions of the aortic root (AO, AC), Left Atrium (LA), and Right Ventricle (RV) compared to Group 1 (p<[0.05– 0.01]).

Importantly, all measured parameters remained within physiological norms accepted for athletes (wall thickness <12 mm, LVEDD <60 mm), indicating that the observed changes represent physiological adaptation rather than pathological remodeling.

Results of two-way ANOVA confirmed that training orientation has an independent statistically significant effect on key morphometric parameters after controlling for the sex factor (for LVEDD: $F=4.21$, $p<0.05$; for LVMM: $F=7.52$, $p<0.01$; for LVPWd: $F=5.86$, $p<0.05$). The sex factor had a strong influence on all absolute parameters ($p<0.01$), but the interaction effect between factors (orientation × sex) was not statistically significant ($p>0.05$), indicating that the pattern of adaptation to training loads is similar in males and females.

Effect sizes (Cohen's d) for comparisons between Groups 3 and 1 showed moderate to large practical significance: LVMM – $d=0.79$ (95% CI 0.42–1.16), LVMI – $d=0.83$ (95% CI 0.46–1.20). These values indicate that the differences in myocardial mass between endurance and speed athletes are not only statistically significant but also clinically meaningful.

Correlation analysis revealed strong positive correlations between LVMM and anthropometric parameters: height ($r=0.72$, $p<0.001$), body weight ($r=0.74$, $p<0.001$), and body surface area (BSA) ($r=0.76$, $p<0.001$). LVMM also correlated strongly with LVEDD ($r=0.74$, $p<0.001$) and LVESD ($r=0.81$, $p<0.001$), indicating that cavity size is the primary determinant of myocardial mass. Moderate correlations were found between LVMM and wall thickness parameters (r=[0.42–0.68], p<[0.05–0.01]).

Analysis of diastolic function revealed that the E/A ratio was within the normal range (>1.0) in all athletes, with no significant differences observed between the groups or between highly qualified and rank athletes. This finding supports the physiological nature of the left ventricular remodeling, as pathological hypertrophy is typically associated with diastolic dysfunction.

Left ventricular dimensions in athletes of different qualifications according to sex are presented in *Table 3*.

Analysis of sex differences showed that all morphometric parameters of the left ventricle were significantly higher in males than in females. These differences correlated with larger anthropometric parameters in males.

Internal dimensions of the heart in athletes of different qualifications depending on gender are presented in *Table 4*.

Assessment of transmitral flow showed preserved diastolic function (E/A > 1.0) across all athletic groups, with no statistically significant intergroup differences or variations related to skill level. The absence of diastolic impairment, even in athletes with the most pronounced cardiac enlargement, confirms the adaptive, non-pathological character of the observed cardiac remodeling.

The obtained results indicate an increase in AO, AC, LA, and RV parameters with the increase in sports mastery in athletes (both males and females). The functional diameter of the aorta is an important clinical and physiological indicator. Its increase indicates enhanced contractility of the left ventricle and the heart as a whole. An increase in the diameter of the aortic fibrous ring leads to an increase in the aortic diameter at the level of the aortic valve cusps. The increase in the anteroposterior dimension of the right ventricle and left atrium in highly qualified athletes can be explained by an increase in venous return to the heart. The dilation of these heart chambers is a consequence of the high physical loads that athletes experience during the training process and competition period. Such adaptations contribute to improved cardiac performance.

Table 3. Internal dimensions of the left ventricle of the heart in athletes of different sports qualifications depending on sex (M±SD)

Parameter	Males		Females	
	Highly qualified (n=45)	Rank athletes (n=30)	Highly qualified (n=43)	Rank athletes (n=31)
IVSd, mm	8.44±0.86	8.14±0.82*	7.80±0.88	7.40±0.92
IVSs, mm	11.34±1.38	10.74±1.30	10.44±1.44	10.00±1.12
LVPWd, mm	8.84±0.94	8.50±0.94*	8.36±1.02	7.76±0.74
LVPWs, mm	15.34±1.38	15.06±1.76*	14.38±1.68	13.64±1.54
LVEDD, mm	50.48±4.52	48.44±4.22	45.88±4.08	44.52±3.88
LVESD, mm	33.62±4.26	31.76±3.14	30.56±3.28	29.06±3.18

Note: * – the difference between highly qualified athletes and rank athletes is not significant ($p>0.05$); for all other parameters, the differences are significant ($p<0.05$);

IVSd – Interventricular Septum thickness in diastole;
IVSs – Interventricular Septum thickness in systole;
LVPWd – Left Ventricular Posterior Wall thickness in diastole;
LVPWs – Left Ventricular Posterior Wall thickness in systole;
LVEDD – Left Ventricular End-Diastolic Dimension;
LVESD – Left Ventricular End-Systolic Dimension.

Table 4. Internal dimensions of the heart in athletes of different sports qualifications depending on sex (M±SD)

Parameter	Males		Females	
	Highly qualified (n=45)	Rank athletes (n=30)	Highly qualified (n=43)	Rank athletes (n=31)
AO, mm	31.02±3.92	28.98±3.22	26.98±2.52	25.48±1.88
AC, mm	22.12±2.58	21.10±2.58	20.48±3.38	18.98±1.58
LA, mm	26.82±3.48	24.18±2.68	24.58±2.62	22.64±2.88
RV, mm	17.98±3.78	15.98±2.68	15.38±3.22	14.24±2.58
MVD, mm	38.62±5.22	38.98±3.88*	36.08±4.82	35.78±3.12*
MVS, mm	28.28±5.02	28.38±3.92*	26.22±4.42	25.58±2.88*

Note: * – the difference between highly qualified athletes and rank athletes is not significant ($p>0.05$); for all other parameters, the differences are significant ($p<0.05$).

AO – AOrtic fibrous ring diameter;
AC – Aortic diameter at the level of the valve Cusps;
LA – Left Atrium anteroposterior dimension;
RV – Right Ventricle anteroposterior dimension;
MVD – Mitral Valve orifice size in Diastole;
MVS – Mitral Valve orifice size in Systole.

Correlation analysis confirmed a strong direct relationship between LVMM and anthropometric parameters: height ($r=0.72$; $p<0.001$), body weight ($r=0.74$; $p<0.001$), BSA ($r=0.76$; $p<0.001$). A high degree of correlation was also found between LVMM and LVEDD ($r=0.74$; $p<0.001$) and LVESD ($r=0.81$; $p<0.001$), which confirms the determining influence of the left ventricular cavity size on the formation of its mass. Moderate correlations were found between LVMM and wall thickness: IVSd ($r=0.68$; $p<0.01$), IVSs ($r=0.52$; $p<0.05$), LVPWd ($r=0.50$; $p<0.05$), LVPWs ($r=0.42$; $p<0.05$).

Discussion

The obtained findings confirm the concept of specificity of adaptive changes in the heart depending on the nature of training loads. The increase in the cavities of the right ventricle and left atrium, as well as the systolic thickening of the left ventricular posterior wall found in athletes of Group 1, is probably associated with the hemodynamic features of maximal intensity work. During sprint exercises, there is a significant increase in intrathoracic pressure and venous return, which creates conditions for increased preload. The enhancement of myocardial contractility in systole is a compensatory mechanism aimed at overcoming increased afterload. This pattern aligns with the concept of "pressure overload", which, according to the Morganroth J. hypothesis, predisposes athletes to concentric remodeling, characterized by wall thickening without a significant increase in cavity size [9; 10]. Fagard R. (2003) [9] notes in his studies that loads with a high static component lead to the predominant development of concentric remodeling, manifested by wall thickening without significant cavity dilation. Belotserkovskiy Z.B. (2005) [10] also points out that athletes in speed-strength sports tend to increase myocardial thickness with relatively stable ventricular cavity sizes. Our data on the absence of a significant increase in LVEDD in Group 1 with the presence of wall thickening in systole are fully consistent with these observations.

The increase in aortic diameter and left atrium size in athletes of Group 2 can be explained by the specificity of speed-strength loads, which require a powerful systolic ejection over a short period. Repeated increases in blood pressure during explosive exercises create conditions for gradual expansion of the aortic ring as an adaptive reaction to hemodynamic impact. Yashchenko A.G. (2002) [14] indicates that the adaptation of the cardiovascular system to speed-strength loads is accompanied by structural changes aimed at optimizing blood ejection under conditions of high peripheral resistance. Hoogsteen J. et al. (2004) [15] in their study of athletes of various specializations also noted an increase in the proximal parts of the aorta in representatives of strength sports, which they explained by increased volume load on the left ventricular outflow tract. While this aortic enlargement is generally considered an adaptive response to increased stroke volume, it raises a clinical question about long-term follow-up. The values observed in our study remained within reported physiological limits for athletes. However, whether such remodeling is a benign adaptation or a potential risk factor for future aortopathy requires longitudinal studies to monitor the elasticity and progression of the aortic root over an athlete's career and into retirement.

The largest morphometric parameters of the heart in athletes of Group 3 are an expected result, confirmed by numerous studies. Maron B.J. & Pelliccia A. (2006) [1] noted that systematic endurance training leads to the formation of the so-called "athlete's heart" with a characteristic increase in cavities and moderate wall thickening. Pelliccia A. et al. (2002) [2] demonstrated that the cumulative effect of long-term aerobic loads manifests in a significant increase in LVEDD and LVMM in highly qualified athletes compared to less trained ones. Utomi V. et al. (2013) [7] consider the increase in LVEDD as the main mechanism of long-term adaptation to dynamic loads, which allows increasing stroke volume without a critical increase in myocardial wall stress. Our obtained increase in LVEDD and LVMM in endurance athletes compared to speed-oriented athletes fully corresponds to the literature data on the formation of eccentric hypertrophy as the most rational mechanism of adaptation to aerobic loads [9]. The ratio of LVEDD increase and wall thickness in our study (proportional increase) indicates the preservation of the normal wall thickness/cavity radius ratio, which is a sign of physiological rather than pathological hypertrophy. Naylor L.H. et al. (2008) [8] in their critical review of the Morganroth hypothesis emphasize the importance of considering individual adaptation features.

It is important to note that despite the significant differences between groups, the absolute values of all parameters remained within the physiological norms accepted for the athletic heart [12; 13]. Maron B.J. & Pelliccia A. (2006) [1] emphasize in their review that the upper limit of physiological hypertrophy for males is a wall thickness of 13 mm, and for females – 11 mm, while LVEDD rarely exceeds 65 mm. Pelliccia A. et al. (2002) [2] based on many years of observations of elite athletes established that exceeding these limits occurs in less than 2% of cases and requires careful differentiation from hypertrophic cardiomyopathy. In none of the athletes we examined did the wall thickness exceed 12 mm, and LVEDD – 60 mm, which allows us to assess the detected changes as a manifestation of rational adaptation, not pathological remodeling. For athletes whose parameters fall into the "gray zone" bordering these limits, additional functional assessment is crucial. In our study, the finding of a normal E/A ratio in all participants, including those with the largest hearts, provides strong supporting evidence for the physiological nature of the adaptation, as early-stage hypertrophic cardiomyopathy is typically characterized by diastolic dysfunction.

The results of two-way ANOVA confirmed that training orientation has an independent effect on cardiac morphology after controlling for sex, with no significant interaction between factors. This indicates that the pattern of adaptation to different training modalities is similar in males and females. The revealed gender differences in morphometric parameters of the heart, which are almost completely leveled after indexing LVMM to BSA, emphasize the importance of using indexed parameters for objective assessment of the presence and degree of LVH, especially when comparing athletes of different genders and anthropometry. Our data suggest that the female heart adapts to training loads according to the same physiological principles as the male heart, but operates within a different range of absolute values determined by smaller body size. After indexing for BSA, these differences diminish, confirming that the primary driver of cardiac size is body habitus, not sex-specific adaptation mechanisms. Weiner R.B. & Baggish A.L. (2012) [12] also point out the need for mandatory consideration of anthropometric data when interpreting echocardiographic parameters, since the absolute values of LVMM and cavity sizes closely correlate with body size. The high correlation coefficients obtained in our study (r=[0.72–0.76]) fully confirm this thesis. This is also consistent with the results of our other study [16], which showed that a comprehensive health assessment combining objective cardiovascular risk factors with subjective quality of life indicators allows for more accurate identification of individuals at increased risk of cardiac disorders. In the context of the current findings, it can be hypothesized that the physiological eccentric and concentric remodeling observed in our athletes, which remained within safe limits, would likely correlate with the high scores on the physical component of health seen in well-adapted athletes. This integration of morphological and subjective data reinforces the concept of the "athlete's heart" as a benign, adaptive phenomenon in the absence of pathological features. Both studies emphasize the importance of a multifactorial approach to assessing the adaptive reserves of the cardiovascular system.

Strong correlations of LVMM with LVEDD (r=0.74) and LVESD (r=0.81) indicate that it is the volumetric characteristics of the left ventricle that make a determining contribution to the formation of its mass. This is consistent with literature data that during physiological adaptation to physical exertion, the increase in LVMM occurs mainly due to cavity dilation, rather than isolated wall thickening [7; 9]. The moderate correlations with wall thickness parameters (r=[0.42–0.68]) suggest that while wall thickening contributes to increased myocardial mass, it plays a secondary role compared to cavity enlargement in this athletic population. The effect sizes calculated for comparisons between endurance and speed athletes (Cohen's d=[0.79–0.83]) indicate that these differences are not only statistically significant but also clinically meaningful, providing quantifiable benchmarks for future studies.

Conclusions

1. The direction of the training process is a determining factor in the formation of the specific phenotype of the "athlete's heart" in track and field athletes. For athletes of Group 3 (predominant development of endurance), the formation of an eccentric type of left ventricular hypertrophy is characteristic, manifested by a significant increase in LVEDD ($p<0.05$) and LVMM ($p<0.01$) against the background of proportional wall thickening. In athletes of Group 1 (speed direction), adaptive changes are mainly limited to systolic thickening of the left ventricular posterior wall ($p<0.05$) without significant cavity dilation. Athletes of Group 2 (speed-strength orientation) demonstrate an intermediate phenotype with significant increases in LVPWd and LA size ($p<[0.05–0.01]$).

2. Increasing sports qualification is accompanied by a significant increase in the main morphometric parameters of the left ventricle. In highly qualified track and field athletes, IVS, LVPW, LVEDD, and LVMM parameters are significantly higher (by [3–20]% depending on the parameter and group) compared to rank athletes, reflecting the deepening of adaptive changes in the myocardium with increasing training.

3. Morphometric parameters of the heart in highly qualified track and field athletes, regardless of specialization, do not exceed the upper limits of the physiological norm (wall thickness <12 mm, LVEDD <60 mm), which allows us to assess the detected changes as a manifestation of rational adaptation, not pathological remodeling. The preservation of normal diastolic function (E/A ratio >1.0) in all athletes further supports the physiological nature of the observed adaptations.

4. A close correlation was established between LVMM and anthropometric parameters (height r=0.72; body weight r=0.74; BSA r=0.76), as well as the dimensions of the left ventricular cavity (LVEDD r=0.74; LVESD r=0.81). This justifies the need for mandatory indexing of LVMM to BSA for correct intergroup and intersex comparative assessment. Two-way ANOVA confirmed that training orientation has an independent effect on cardiac morphology after controlling for sex, with similar adaptation patterns in males and females.

5. The preservation of normal diastolic function (E/A ratio) in all athletes, even those with the most pronounced cardiac enlargement, serves as a key differentiator between physiological adaptation and pathological conditions like hypertrophic cardiomyopathy. The moderate to large effect sizes observed for LVMM and LVMI (Cohen's d=[0.79–0.83]) indicate that the differences between endurance and speed athletes are clinically meaningful. A multifactorial approach combining indexed morphometric parameters with functional assessment is essential for accurate diagnosis and risk stratification in sports cardiology.

Prospects for Further Research

Further research should be directed to studying the dynamics of morphometric parameters of the left ventricle in the process of long-term training of athletes to determine critical periods of hypertrophy formation and the risk of transition from physiological to pathological hypertrophy. The implementation of advanced imaging techniques, such as Speckle Tracking Echocardiography (strain analysis) and 3D echocardiography, is promising for detecting subclinical changes in myocardial function that may precede pathological remodeling. The search for genetic markers associated with a predisposition to excessive LVH is also promising for individualizing the training process and preventing cardiovascular complications in high-performance sports. In addition, the issue of reversibility of detected morphological changes in the readaptation period after the end of a sports career requires further study. Finally, longitudinal studies are needed to clarify the long-term clinical significance of aortic root dilation in strength athletes and to establish evidence-based guidelines for monitoring cardiovascular health in this population.

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Authors' Contributions

Contribution Authors	A	B	C	D	E	F
Burdina V.R.	+	+	+	+	+	+
Danylchenko S.I.	+		+			+
Golovchenko I.V.				+		+
Morozenko D.V.				+		+
Shevchenko A.S.	+	+	+	+	+	+
Cherkova N.V.			+			+
Dushik L.N.				+		+

Notes: A – concept; B – design; C – data collection;
D – statistical processing and interpretation of data;
E – writing or critical editing of the article;
F – approval of the final version for publication and agreement to be responsible for all aspects of the work.

Declarations

Conflict of interest is absent.

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The authors of the manuscript state that in the process of conducting research, preparing, and editing this manuscript, they did not use any generative AI tools or services to perform any of the tasks listed in the Generative AI Delegation Taxonomy (GAIDeT, 2025). All stages of work (from the development of the research concept to the final editing) were carried out without the involvement of generative artificial intelligence, exclusively by the authors.

References

1. Maron BJ, Pelliccia A. The heart of trained athletes: cardiac remodeling and the risks of sports, including sudden death. Circulation. 2006;114(15):1633-44. DOI: 10.1161/CIRCULATIONAHA.106.613562. PMID: 17030703.

2. Pelliccia A, Di Paolo FM, Maron BJ. The athlete's heart: remodeling, electrocardiogram and preparticipation screening. Cardiol Rev. 2002;10(2):85-90. DOI: 10.1097/00045415-200203000-00006. PMID: 11890291.

3. Fagard R. Athlete's heart. Heart. 2003;89(12):1455-61. DOI: 10.1136/heart.89.12.1455. PMID: 14617564.

4. Sharma S, Merghani A, Mont L. Exercise and the heart: the good, the bad, and the ugly. Eur Heart J. 2015;36(23):1445-53. DOI: 10.1093/eurheartj/ehv090. PMID: 25825044.

5. Hsieh PN, Jeevanandam V, Palaniyandi SS, Hajjar RJ, Homma S, Hardarson T, et al. Athlete's Heart Revisited: Historical, Clinical, and Molecular Perspectives. Circ Res. 2025;137(2):231-54. DOI: 10.1161/CIRCRESAHA.125.325651.

6. Basavarajaiah S, Boraita A, Whyte G, Wilson M, Carby L, Shah A, et al. Ethnic differences in left ventricular remodelling in highly-trained athletes: relevance to differentiating physiologic left ventricular hypertrophy from hypertrophic cardiomyopathy. J Am Coll Cardiol. 2008;51(23):2256-62. DOI: 10.1016/j.jacc.2007.12.061. PMID: 18534275.

7. Utomi V, Oxborough D, Whyte GP, Somauroo J, Sharma S, Shave R, et al. Systematic review and meta-analysis of training mode, imaging modality and body size influences on the morphology and function of the male athlete's heart. Heart. 2013;99(23):1727-33. DOI: 10.1136/heartjnl-2012-303465. PMID: 23474689.

8. Naylor LH, George K, O'Driscoll G, Green DJ. The athlete's heart: a contemporary appraisal of the 'Morganroth hypothesis'. Sports Med. 2008;38(1):69-90. DOI: 10.2165/00007256-200838010-00006. PMID: 18081368.

9. Eriksson LMJ, Hedman K, Åström-Aneq M, Henein MY, Larsson A, Johansson J, et al. Evidence of Left Ventricular Cardiac Remodeling After 6 Weeks of Sprint Interval Training. Scand J Med Sci Sports. 2024;34(12):e70007. DOI: 10.1111/sms.70007.

10. Galderisi M, Cardim N, D'Andrea A, Bruder O, Cosyns B, Davin L, et al. The multi-modality cardiac imaging approach to the Athlete's heart: an expert consensus of the European Association of Cardiovascular Imaging. Eur Heart J Cardiovasc Imaging. 2015;16(4):353-63. DOI: 10.1093/ehjci/jeu323. PMID: 25787360.

11. Pelliccia A, Caselli S, Sharma S, Basso C, Bax JJ, Corrado D, et al. European Association of Preventive Cardiology (EAPC) and European Association of Cardiovascular Imaging (EACVI) joint position statement: recommendations for the indication and interpretation of cardiovascular imaging in the evaluation of the athlete's heart. Eur Heart J. 2018;39(21):1949-69. DOI: 10.1093/eurheartj/ehx532. PMID: 29029207.

12. Weiner RB, Baggish AL. Exercise-induced cardiac remodeling. Prog Cardiovasc Dis. 2012;54(5):380-6. DOI: 10.1016/j.pcad.2012.01.006. PMID: 22386288.

13. D'Andrea A, Riegler L, Cocchia R, Scarafile R, Salerno G, Gravino R, et al. Left atrial volume index in highly trained athletes. Am Heart J. 2010;159(6):1155-61. DOI: 10.1016/j.ahj.2010.03.036. PMID: 20569733.

14. Hoogsteen J, Hoogeveen A, Schaffers H, Wijn PF, van der Wall EE. Myocardial adaptation in different endurance sports: an echocardiographic study. Int J Cardiovasc Imaging. 2004;20(1):19-26. DOI: 10.1023/B:CAIM.0000013134.45097.d5. PMID: 15055944.

15. Pluim BM, Zwinderman AH, van der Laarse A, van der Wall EE. The athlete's heart: a meta-analysis of cardiac structure and function. Circulation. 2000;101(3):336-44. DOI: 10.1161/01.cir.101.3.336. PMID: 10645932.

16. Burdina VR, Danylchenko SI, Yesselbayeva AK, Golovchenko IV, Morozenko DV, Aravitska MG, et al. Suboptimal health and cardiovascular risk: Questionnaire-based assessment using SHSQ-25 and SF-36. Inter Collegas. 2025;12(3):12p. DOI: 10.35339/ic.2025.12.3.bdy.

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