

Reversibility of Cardiac Adaptations in Elite Combat Athletes: A Three-Year Echocardiographic Study

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Abstract: Combat sports (boxing, wrestling, taekwondo) induce marked cardiac adaptations; however, their reversibility with reduced training intensity remains insufficiently studied. The aim of this study was to evaluate longitudinal changes in echocardiographic parameters among elite combat athletes during the period 2022–2025. The study included 125 athletes (boxing: $n = 50$, wrestling: $n = 54$, taekwondo: $n = 21$). Transthoracic echocardiography was performed in 2022 (high-intensity training phase) and in 2025 (routine training phase). The following parameters were assessed: left ventricular myocardial mass (LVMM), LVMM index (LVMMI), end-diastolic volume (EDV), stroke volume (SV), ejection fraction (EF), and peak diastolic filling velocities (E, A). Statistical analysis was performed using the Wilcoxon test ($p < 0.05$).

All groups demonstrated regression of cardiac hypertrophy (LVMM: -15.5% , LVMMI: -15.3%) and chamber volumes (EDV: -14.9% , SV: -17.8%) ($p < 0.05$). The most pronounced changes were observed in taekwondo athletes (LVMM: -18.5% , LVMMI: -18.4%), and the least in wrestlers (LVMM: -10.5%). Diastolic function decreased significantly (E: -22.2% , A: -32.9%). EF declined slightly (-2.3%) but remained within normal limits ($> 60\%$).

Reduced training intensity leads to regression of cardiac adaptations in combat athletes, with distinct sport-specific differences. The findings emphasize the importance of regular echocardiographic monitoring to optimize cardiovascular health in athletes.

Keywords: athlete's heart, combat sports, echocardiography, myocardial hypertrophy, reversibility of adaptations

Introduction

Combat sports such as boxing, wrestling, and taekwondo impose unique demands on the cardiovascular system, resulting from a combination of high-intensity aerobic and anaerobic workloads, strength training, and episodes of maximal physical exertion [10, 11]. These training loads lead to adaptive cardiac remodeling, known as the “athlete's heart,” characterized by an increase in left ventricular myocardial mass (LVMM), enlargement of cardiac chambers, and alterations in diastolic function [14, 16, 5]. Although such adaptations are generally considered physiological, prolonged exposure to intensive training may increase the risk of cardiovascular complications, particularly during abrupt reductions in training intensity, such as in off-season or detraining periods [1].

Cardiovascular adaptations in combat sports remain less thoroughly studied compared to endurance- or strength-oriented disciplines, despite their unique combination of aerobic endurance, anaerobic power, and strength components [4, 17]. Boxing involves high-intensity interval efforts, wrestling emphasizes strength and isometric contractions, while taekwondo relies on aerobic endurance and explosive movements. These differences may result in sport-specific cardiac adaptations, which are still insufficiently explored—especially in longitudinal studies assessing temporal changes in relation to training intensity.

Gender differences further complicate the understanding of cardiac adaptations in combat sports. Female athletes generally exhibit less pronounced left ventricular hypertrophy and smaller cardiac

chamber dimensions compared to males, which may be attributed to differences in training volume, hormonal status, and baseline cardiac morphology [4, 13, 6]. However, long-term data on female combat athletes remain limited, hindering the development of targeted monitoring and training strategies for this group. The period of reduced training intensity (e.g., the off-season) offers a unique opportunity to study the reversibility of cardiac adaptations, which is essential for distinguishing physiological remodeling from pathological changes [14].

The aim of this study was to evaluate longitudinal changes in cardiac structure and function among elite combat athletes (boxers, wrestlers, and taekwondo practitioners) between 2022 and 2025—a period characterized by the transition from high-intensity pre-competitive training in 2022 to routine moderate-intensity training during 2023–2025.

Materials and Methods

A total of 125 elite combat athletes representing three disciplines participated in the study: boxing (n = 50), wrestling (n = 54), and taekwondo (n = 21). The sample was stratified by sex and sport to analyze gender- and sport-specific features of cardiac adaptation. The overall cohort included 79 men and 46 women. Detailed demographic and training characteristics are presented in Table 1.

Table 1. Demographic data and training characteristics

Group	Sex	n	Median age, 2022 (years) [Q1; Q3]	Median age, 2025 (years) [Q1; Q3]	Training experience (years, median [Q1; Q3])
Boxing	Men	31	18 [15; 20]	21 [18; 23]	6 [4; 8]
	Women	19	17 [15; 19]	20 [18; 22]	5 [3; 7]
	Total	50	17.5 [15; 20]	20.5 [18; 23]	5.5 [4; 7.5]
Wrestling	Men	36	19 [18; 21]	22 [21; 24]	7 [5; 9]
	Women	18	18.5 [16.75; 21]	21.5 [19.75; 24]	6 [4; 8]
	Total	54	19 [17.75; 21]	22 [20.75; 24]	6.5 [4.5; 8.5]
Taekwondo	Men	12	17 [16; 17.75]	20 [19; 20.75]	5 [3; 6]
	Women	9	17 [15.5; 18]	20 [17.5; 21]	4 [3; 5]
	Total	21	17 [16; 17.5]	20 [18.5; 20.5]	4.5 [3; 5.5]
Total	Men	79	18 [17; 20]	21 [20; 23]	6 [4; 8]
	Women	46	17 [16; 19]	20 [19; 22]	5 [3; 7]
	Total	125	18 [16; 20]	21 [19; 23]	5.5 [4; 7.5]

In 2022, participants were aged 15–21 years (median 18 [16; 20]), and by 2025, their median age had increased to 21 years [19; 23], reflecting natural aging. The mean training experience across all athletes was 5.5 years [4; 7.5], with the longest duration observed in wrestlers (6.5 years [4.5; 8.5]) and the shortest in taekwondo athletes (4.5 years [3; 5.5]).

All participants were professional athletes engaged in pre-competitive high-intensity training in 2022, combining aerobic, anaerobic, and strength loads. During 2023–2025, the training regimen was routine and moderate in intensity, serving a maintenance purpose.

Inclusion criteria were:

1. Age between 15 and 24 years;
2. Professional status in boxing, wrestling, or taekwondo;
3. No diagnosed cardiovascular diseases;
4. No use of medications affecting cardiac function.

Exclusion criteria included chronic diseases, injuries preventing training, or refusal to participate in follow-up assessment in 2025. The study was approved by the local ethics committee, and all participants provided written informed consent.

Echocardiography Methods

Cardiac structural and functional parameters were evaluated using transthoracic echocardiography (TTE) performed on a Vinno A6 system (Vinno, China) with a 2–4 MHz sector probe. The examinations were conducted in accordance with the recommendations of the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI) [9].

TTE was performed with participants in the left lateral decubitus position in the morning, following at least 12 hours of rest from training to minimize the influence of acute exercise effects. Standard imaging planes were used:

- Parasternal (long- and short-axis views)
- Apical (four-, two-, and three-chamber views).
- Normative values for athletes were based on literature data:
- End-diastolic volume (EDV) > 160 mL and end-systolic volume (ESV) > 70 mL were considered abnormal in the general population but acceptable in athletes (up to 200 mL in men and 150 mL in women) [15].
- Left ventricular mass index (LVMI) > 115 g/m² in men and > 95 g/m² in women was considered indicative of myocardial hypertrophy in athletes.

To ensure reproducibility, all measurements were performed by a single certified echocardiography specialist. In cases of measurement discrepancies (e.g., in EDV or ESV), repeated measurements were performed and averaged. The device was calibrated before each examination.

Statistical Analysis

Data are presented as medians with interquartile ranges [Q1; Q3] due to the non-normal distribution assumed based on the sample characteristics. To assess changes in parameters between 2022 and 2025 within each subgroup, the paired nonparametric Wilcoxon signed-rank test was applied. The level of statistical significance was set at $p < 0.05$. For intergroup comparisons (boxing vs wrestling, boxing vs taekwondo, wrestling vs taekwondo), the Mann–Whitney *U*-test with Bonferroni correction ($p < 0.0167$) was used. Statistical processing was performed using **IBM SPSS Statistics (version 26)** and **R (version 4.2.0)**.

Results

In the combined group of **boxers**, statistically significant changes were observed in all echocardiographic parameters ($p < 0.05$) (Table 2). The most pronounced decreases were found in the **left ventricular myocardial mass index (LVMMI: –17.0%, $p = 0.0001$)**, **left ventricular myocardial mass (LVM: –13.0%, $p = 0.0020$)**, **end-diastolic volume (EDV: –12.6%, $p = 0.0047$)**, and **stroke volume (SV: –12.2%, $p = 0.0009$)**. The **interventricular septum thickness (IVS: –8.3%, $p = 0.0003$)**, **posterior wall thickness (PWT: –9.0%, $p = 0.0004$)**, **end-systolic volume (ESV: –11.3%, $p = 0.0327$)**, and **indexed EDV (iEDV: –13.0%, $p = 0.0001$)** also decreased. The **ejection fraction (EF)** declined slightly (–1.6%, $p < 0.0001$) but remained within the normal range (> 60%). Peak early (E: –11.2%, $p < 0.0001$) and late (A: –13.8%, $p = 0.0001$) diastolic filling velocities indicated alterations in myocardial relaxation [4].

Table 2. Dynamics of echocardiographic parameters in boxers (2022 vs. 2025)

Parameter	2022, median [Q1; Q3]	2025, median [Q1; Q3]	Change, %	p
IVS, cm	0.90 [0.80; 0.9725]	0.825 [0.745; 0.90]	–8.3	0.0003
PWT, cm	0.89 [0.795; 0.97]	0.81 [0.7275; 0.88]	–9.0	0.0004
LVM, g	159.33 [126.27; 200.18]	138.65 [112.78; 160.05]	–13.0	0.0020
LVMMI, g/m ²	92.5 [76.9; 104.6]	76.75 [67.3; 87.38]	–17.0	0.0001

Parameter	2022, median [Q1; Q3]	2025, median [Q1; Q3]	Change, %	p
EDV, mL	107.65 [96.25; 127.4]	94.05 [86.38; 109.0]	-12.6	0.0047
ESV, mL	39.0 [33.88; 45.25]	34.6 [31.9; 42.0]	-11.3	0.0327
iEDV, mL/m ²	61.63 [55.51; 68.64]	53.59 [49.18; 61.26]	-13.0	0.0001
SV, mL	68.1 [61.5; 83.0]	59.8 [54.33; 68.5]	-12.2	0.0009
EF, %	64.05 [63.0; 64.8]	63.0 [62.48; 63.5]	-1.6	<0.0001
E, cm/s	0.89 [0.83; 1.00]	0.79 [0.74; 0.85]	-11.2	<0.0001
A, cm/s	0.58 [0.47; 0.69]	0.50 [0.43; 0.54]	-13.8	0.0001

In the combined group of **wrestlers**, significant changes ($p < 0.05$) were observed in all parameters except for IVS (-5.3% , $p = 0.0879$) (Table 3). The most pronounced decreases were noted in **peak late diastolic velocity (A: -35.1% , $p < 0.0001$)** and **early diastolic velocity (E: -23.8% , $p < 0.0001$)**. **LVM (-10.5% , $p = 0.0342$)**, **LVMMI (-8.2% , $p = 0.0105$)**, **EDV (-10.5% , $p = 0.0013$)**, **ESV (-12.7% , $p = 0.0414$)**, **iEDV (-13.9% , $p < 0.0001$)**, and **SV (-18.0% , $p = 0.0001$)** also decreased. **PWT** decreased by 6.4% ($p = 0.0372$). **EF** declined by 3.3% ($p < 0.0001$) but remained within the normal range. The lack of significance for IVS may be due to its lower sensitivity to training load reduction in wrestlers [14].

Table 3. Dynamics of echocardiographic parameters in wrestlers (2022 vs. 2025)

Parameter	2022, median [Q1; Q3]	2025, median [Q1; Q3]	Change, %	p
IVS, cm	0.95 [0.82; 1.02]	0.90 [0.80; 1.00]	-5.3	0.0879
PWT, cm	0.94 [0.84; 1.01]	0.88 [0.80; 1.00]	-6.4	0.0372
LVM, g	180.47 [141.19; 216.44]	161.55 [123.86; 193.14]	-10.5	0.0342
LVMMI, g/m ²	95.40 [81.51; 110.08]	87.60 [71.98; 99.85]	-8.2	0.0105
EDV, mL	127.0 [102.5; 146.25]	104.85 [92.10; 126.75]	-10.5	0.0013
ESV, mL	45.5 [36.75; 52.0]	39.7 [33.95; 48.85]	-12.7	0.0414
iEDV, mL/m ²	66.76 [60.40; 74.35]	57.45 [51.21; 66.65]	-13.9	<0.0001
SV, mL	80.0 [64.0; 92.25]	65.65 [58.35; 79.15]	-18.0	0.0001
EF, %	64.48 [61.61; 66.30]	62.35 [60.6; 63.4]	-3.3	<0.0001
E, cm/s	1.135 [1.08; 1.21]	0.865 [0.81; 0.94]	-23.8	<0.0001
A, cm/s	0.87 [0.80; 0.93]	0.565 [0.45; 0.67]	-35.1	<0.0001

In the combined group of **taekwondo athletes**, significant changes ($p < 0.05$) were found in all parameters except for **ESV (-11.9% , $p = 0.0824$)** (Table 4). The most prominent decreases were noted in **A (-28.6% , $p < 0.0001$)**, **E (-26.3% , $p < 0.0001$)**, **LVM (-18.5% , $p = 0.0014$)**, and **LVMMI (-18.4% , $p = 0.0002$)**. **IVS (-13.8% , $p = 0.0003$)**, **PWT (-14.6% , $p = 0.0010$)**, **EDV (-15.5% , $p = 0.0034$)**, **iEDV (-12.5% , $p = 0.0019$)**, and **SV (-17.2% , $p = 0.0006$)** also decreased. **EF** declined by 5.0% ($p = 0.0007$) but remained within normal limits.

Table 4. Dynamics of echocardiographic parameters in taekwondo athletes (2022 vs. 2025)

Parameter	2022, median [Q1; Q3]	2025, median [Q1; Q3]	Change, %	p
IVS, cm	0.94 [0.81; 1.03]	0.81 [0.755; 0.875]	-13.8	0.0003
PWT, cm	0.96 [0.805; 1.05]	0.82 [0.745; 0.885]	-14.6	0.0010
LVM, g	167.24 [126.02; 211.93]	136.42 [113.89; 158.13]	-18.5	0.0014
LVMMI, g/m ²	84.48 [72.98; 104.24]	69.0 [65.3; 78.75]	-18.4	0.0002
EDV, mL	113.0 [100.5; 129.5]	95.5 [89.3; 111.1]	-15.5	0.0034
ESV, mL	42.0 [35.0; 45.0]	37.0 [33.4; 41.35]	-11.9	0.0824
iEDV, mL/m ²	59.84 [54.28; 68.87]	52.42 [49.53; 59.74]	-12.5	0.0019
SV, mL	71.0 [65.5; 83.5]	58.8 [56.1; 70.0]	-17.2	0.0006
EF, %	65.67 [62.61; 66.51]	62.4 [61.75; 63.5]	-5.0	0.0007

E, cm/s	1.18 [1.10; 1.23]	0.87 [0.815; 0.92]	-26.3	<0.0001
A, cm/s	0.84 [0.75; 0.93]	0.60 [0.52; 0.685]	-28.6	<0.0001

In the **combined sample**, all echocardiographic parameters demonstrated statistically significant changes ($p < 0.05$) (Table 5). The most pronounced decreases were observed in **A** (**-32.9%**, $p < 0.0001$), **E** (**-22.2%**, $p < 0.0001$), **LVM** (**-15.5%**, $p < 0.0001$), and **LVMMI** (**-15.3%**, $p < 0.0001$). **EDV** (**-14.9%**, $p < 0.0001$), **iEDV** (**-12.9%**, $p < 0.0001$), and **SV** (**-17.8%**, $p < 0.0001$) also decreased, along with **IVS** (**-10.6%**, $p < 0.0001$), **PWT** (**-9.8%**, $p < 0.0001$), and **ESV** (**-9.8%**, $p = 0.0016$). The **ejection fraction (EF)** decreased modestly (**-2.3%**, $p < 0.0001$), remaining within the physiological range ($> 60\%$) [15].

Table 5. Dynamics of echocardiographic parameters in the combined group of athletes (2022 vs. 2025)

Parameter	2022, median [Q1; Q3]	2025, median [Q1; Q3]	Change, %	p
IVS, cm	0.94 [0.81; 1.01]	0.84 [0.78; 0.94]	-10.6	<0.0001
PWT, cm	0.92 [0.805; 1.01]	0.83 [0.76; 0.92]	-9.8	<0.0001
LVM, g	169.23 [136.22; 209.83]	143.07 [117.36; 178.02]	-15.5	<0.0001
LVMMI, g/m ²	91.90 [77.70; 108.13]	77.80 [67.20; 92.85]	-15.3	<0.0001
EDV, mL	115.0 [98.8; 136.5]	97.9 [87.35; 117.0]	-14.9	<0.0001
ESV, mL	41.0 [35.0; 49.0]	37.0 [33.0; 43.0]	-9.8	0.0016
iEDV, mL/m ²	62.66 [56.59; 71.44]	54.59 [50.03; 62.42]	-12.9	<0.0001
SV, mL	75.4 [63.95; 88.0]	62.0 [55.45; 75.1]	-17.8	<0.0001
EF, %	64.2 [62.8; 65.84]	62.7 [61.8; 63.5]	-2.3	<0.0001
E, cm/s	1.08 [0.94; 1.17]	0.84 [0.78; 0.89]	-22.2	<0.0001
A, cm/s	0.79 [0.615; 0.89]	0.53 [0.455; 0.62]	-32.9	<0.0001

Discussions

The results of the present study demonstrate significant changes in echocardiographic parameters among elite combat sport athletes (boxing, wrestling, taekwondo) from 2022 to 2025, associated with a transition from high-intensity pre-competition training to routine moderate-intensity training. The most pronounced changes were observed in peak diastolic filling velocities (E: -22.2%, A: -32.9%), left ventricular myocardial mass (LVMM: -15.5%), left ventricular mass index (LVMI: -15.3%), end-diastolic volume (EDV: -14.9%), and stroke volume (SV: -17.8%) across the entire cohort ($n = 125$). These findings support the hypothesis of regression in cardiac adaptations following reduced training intensity, consistent with the concept of the “athlete’s heart” [15].

The regression of myocardial hypertrophy observed in all groups (LVMM: -13.0% in boxers, -10.5% in wrestlers, -18.5% in taekwondo athletes) aligns with existing literature indicating the reversibility of structural cardiac adaptations with decreased physical load [1, 3]. The most substantial reductions in LVMM and LVMI in taekwondo athletes (-18.5% and -18.4%) may be attributed to their training regimen, which includes a significant aerobic component leading to chamber dilation and hypertrophy during intensive training, followed by a more marked regression during detraining [10, 8]. In contrast, the smaller decrease in LVMM among wrestlers (-10.5%) and the absence of a significant change in interventricular septal thickness (-5.3%, $p = 0.0879$) may be due to the predominance of isometric exercises, which induce more stable hypertrophy less prone to regression [14].

Changes in diastolic function, reflected in decreased E and A velocities, were most pronounced in wrestlers (E: -23.8%, A: -35.1%) and taekwondo athletes (E: -26.3%, A: -28.6%), indicating improved myocardial relaxation with reduced training intensity. These findings are consistent with previous studies showing that intensive training increases myocardial stiffness, while reduced workloads promote the recovery of diastolic compliance [12]. Among boxers, the changes in E (-11.2%) and A (-13.8%) were less pronounced, possibly reflecting their lower dependence on sustained aerobic loading compared to taekwondo.

The observed decreases in EDV (-14.9%) and SV (-17.8%) across the entire cohort suggest a reduction in cardiac chamber volumes, again consistent with the concept of reversible athlete's heart [1]. Taekwondo athletes exhibited the most notable decrease in EDV (-15.5%), likely due to their initially larger chamber volumes resulting from aerobic conditioning. Wrestlers showed a less marked decrease (-10.5%), possibly reflecting the influence of strength-oriented training, which has a smaller effect on chamber dilation [10]. The slight reduction in ejection fraction (EF: -2.3%, $p < 0.0001$) remained within physiological limits ($>60\%$), confirming the absence of pathological changes in systolic function [15, 2].

The lack of significant changes in end-systolic volume (ESV) among taekwondo athletes (-11.9%, $p = 0.0824$) may reflect the lower sensitivity of this parameter to reduced training load in this group, as well as the relatively small sample size ($n = 21$). Similarly, the absence of significance for interventricular septal thickness in wrestlers ($p = 0.0879$) may indicate the persistence of hypertrophy induced by isometric exercise, as previously noted [15].

The clinical relevance of these findings lies in confirming the reversibility of cardiac adaptations in combat athletes, which is crucial for differentiating physiological hypertrophy from pathological conditions such as hypertrophic cardiomyopathy [15]. The regression of parameters such as LVMM and EDV with reduced training intensity highlights the importance of regular echocardiographic monitoring for assessing athletes' cardiac health, particularly during off-season periods or post-retirement. The observed sport-specific differences (e.g., more pronounced regression in taekwondo athletes) emphasize the need for sport-specific approaches to cardiac monitoring and training management.

Future studies should include larger samples, especially for taekwondo athletes, and consider the influence of training program characteristics (e.g., proportions of aerobic and strength components) on cardiac dynamics over time.

Conclusions

The present study confirmed the reversibility of cardiac adaptations in elite combat sport athletes (boxing, wrestling, taekwondo) following reduced training intensity between 2022 and 2025. All groups demonstrated significant regression of myocardial hypertrophy (LVMM: -15.5%, LVMI: -15.3%), reductions in chamber volumes (EDV: -14.9%, SV: -17.8%), and alterations in diastolic function (E: -22.2%, A: -32.9%) ($p < 0.05$). The most pronounced changes were observed in taekwondo athletes (LVMM: -18.5%, LVMI: -18.4%), likely due to the predominance of aerobic loads in their training regimen. Wrestlers showed less pronounced regression (LVMM: -10.5%), which may reflect the stability of isometric load-induced adaptations.

These findings emphasize the importance of regular echocardiographic monitoring to assess athletes' cardiac health, especially during the off-season or after retirement, for distinguishing physiological hypertrophy from pathological states. The sport-specific differences in adaptation regression underline the need for individualized approaches to training management and cardiac evaluation in combat sports. Further research should focus on the effects of training programs on cardiac parameters, including intergroup comparisons and the assessment of additional indices such as atrial and right ventricular dimensions, to achieve a more comprehensive understanding of cardiac adaptations in these disciplines.

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