

Heart Adaptation Mechanisms in Elite Female Athletes: Comparison With Healthy Individuals and Time of Training

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Abstract

Background: Intense continuous exercise provokes adaptive remodeling phenotypes in athletes, the parameters of which can be evaluated through conventional echocardiography and myocardial deformation. We compared myocardial remodeling in female athletes (athlete group) with sedentary women of the same age range (control group) and between older and younger athletes.

Methods: A total of 57 female soccer players and 25 healthy sedentary women were selected. The athlete group was subdivided into a main group and those under 17 years of age (< 17 group). The dimensions and systolic and diastolic function of the cardiac chambers and myocardial deformation (longitudinal and circumferential, as well as radial strain and rotational mechanics) was determined through echocardiography, using the Z statistic with a significance level of $p < 0.05$.

Results: The mean age of the athlete, control, main, and < 17 groups was 22.1 (SD, 6.3); 21.2 (SD, 5.0); 26.5 (SD, 5.1); 16.5 (SD, 0.6) years, respectively. Weight, body mass index and heart rate were lower in the athlete group. Wall thickness, left ventricular mass index, left atrial (LA) volume, ejection fraction, and right ventricular dimensions were higher in athlete group, but remained within normal ranges. Regarding myocardial deformation, there was decreased radial strain, basal rotation, apical rotation, and twisting in the athlete group, suggesting a contractile reserve mechanism. These parameters were lesser in the main athlete group, who also had greater wall thickness, greater volume in the left atrium (LA) and larger size in the right ventricle (RV), suggesting that increased contractile reserve is related to longer time spent in the sport.

Conclusions: In female athletes who had undergone intense long-term training, we observed adaptive remodeling of the cardiac chambers and increased contractile reserve (at rest), and these changes were more pronounced in those with longer involvement in the sport.

Keywords: Echocardiography; Atrial Remodeling; Athletes.

Introduction

Intense sustained exercise leads to adaptive remodeling in the cardiac cavities. However, remodeling mechanisms differ according to activity type, as postulated by Morganroth in 1975:¹ anaerobic exercise (strength and short-duration) causes concentric remodeling, while aerobic exercise (resistance and long-duration) causes eccentric remodeling. In different sports there are many combinations between strength and resistance, resulting in combined phenotypes. Soccer, for example, involves an estimated 70% aerobic and 30% anaerobic activity.²

In some athletes, remodeling results in different degrees of hypertrophy or myocardial dilation, sometimes resulting in a difficult differential diagnosis of hypertrophic or dilated cardiomyopathies. Based on research and diagnostic criteria, eligibility criteria for elite athletes with cardiac alterations have now been developed.³ The selection of these criteria is extremely important, since the prevalence of sudden death among athletes is high.⁴ In most athletes, however, physiological cardiac remodeling occurs within normal limits or below pathological values. The threshold between pathological and athletic hypertrophy is ≥ 16 mm for the interventricular septum. Athletes, in general, have a septal thickness ≤ 12 mm, with a septal thickness 13–15 mm and a septum/wall ratio < 1.3 considered a “gray zone”.⁵ As a further complication, the adaptive response to exercise is lower in women.⁶

Material and methods

To verify the adaptive response to habitual exercise at an intense level, we compared elite female athletes from the

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national women's soccer team (athlete group), with healthy sedentary women of the same age range (control group).

To determine changes that occur as a function of time, we divided the athletes into two groups: one of players from the main team (main group) and another of players from the under-17 team (< 17 group).

The analysis was based on resting echocardiography, measuring and comparing several echocardiographic parameters. All parameters were analyzed according to current American Society of Echocardiography guidelines.⁷

Using transthoracic echocardiography, we analyzed a total of 57 athletes, which, as mentioned above, were subdivided into 2 groups: 32 older athletes (main group) and 25 younger athletes (< 17 group). A control group of 25 healthy sedentary women from the same age range was compared with the combined athlete group.

The analyzed demographic parameters were age, weight, height, body surface area, and body mass index. In a break between training sessions, we used transthoracic echocardiography at rest to determine heart rate, left ventricle (LV) diameter, end-diastolic thickness of the interventricular septum and free posterior wall, LV end-diastolic volume, ejection fraction, diameters of the aorta and left atrium, baseline right ventricle (RV) diameter, and end-expiratory inferior vena cava diameter. We calculated the LV mass, relative LV wall thickness, and left atrial (LA) volume. With Doppler ultrasound, we measured mitral flow, E wave, and A wave velocities, while with tissue Doppler imaging we measured the mean e' wave to peak mitral annulus velocity.

Using speckle tracking, a measure myocardial deformation, we determined: LV global longitudinal strain, LV systolic strain rate, and LV early diastolic strain rate, LV circumferential and radial strain, RV strain and longitudinal strain rate, baseline LV rotation, LV apical rotation, LA longitudinal strain, and right atrial (RA) longitudinal strain. The following parameters were indexed to body surface area: LV end-diastolic volume, LV mass, and LA volume. Twisting was calculated from LV basal rotation and apical rotation, which were obtained through speckle tracking.

The exams were performed by the same operator with a CX50 ultrasound machine (Philips Healthcare, Andover, MA, USA) and QLAB 15 software. In this quantitative descriptive study, statistical analysis was performed using the Z test for independent samples. Numerical data were analyzed in BioEstat 5.0, determining the mean, SD, and statistical difference with a significance level of < 5%. Sample variance was estimated to verify homogeneity.

Results

We divided the analysis into two parts: the first was a comparison of the combined athlete group with healthy controls, ie, sedentary women of the same age range; while the second was a comparison between the main and under-17 teams.

Table 1 compares echocardiographic data between the athlete and control groups, while Table 2 compares

myocardial deformation parameters between the athlete and control groups. Table 3 compares echocardiographic data between the main and < 17 athlete groups, while Table 4 compares myocardial deformation parameters between the main and < 17 athlete groups.

Regarding echocardiographic parameters between the athlete and control groups, heart rate was significantly lower in the athlete group. End-diastolic thickness of the interventricular septum and free posterior wall, LA diameter, and RV diameter were significantly greater in the athlete group. LV mass index, LV diastolic volume, and indexed LA volume and LV ejection fraction were significantly higher among athletes than controls. In 42% of the athlete group, the indexed LV volume was > 61 mL/m², which was considered the upper limit of normality, although the LV mass index and relative wall thickness were not characteristic of hypertrophy.

Regarding myocardial deformation in the athlete and control groups, LV global radial strain, RV global longitudinal strain, and LV basal and apical rotation and twisting were significantly greater in the control group.

Between the main and < 17 athlete groups, LV diastolic diameter was significantly greater in < 17 group, while end-diastolic thickness of the interventricular septum and free posterior wall, as well as LA and RV diameter, were significantly greater in the main group. Relative wall thickness was greater in the main group, while indexed LA volume was greater in the < 17 group. In the main group, mitral E wave velocity was significantly lower, mitral A wave velocity was significantly higher, and the E/A ratio was significantly lower, with no difference in the e' wave velocities of the mitral annulus or the E/e' ratio. Regarding strain parameters, LV longitudinal systolic and diastolic strain rate, LV radial strain, RV longitudinal strain rate, apical rotation, and twisting were significantly higher in the < 17 group.

Discussion

Comparing elite female athletes with healthy sedentary women of the same age range yielded some important observations: the athletes had lower weight, lower body mass index, and thinner bodies, but no difference in height. Thus, body mass index, rather than body surface area, allowed more efficient distinction of this body type, which has been observed in previous studies of obese and thin patients.^{8,9}

The differences between the athlete and control groups show the heart's physiological adaptation to habitual intense exercise, such as lower heart rate, greater LV wall thickness and increased LA and RV diameters. Increased RV diameter, a frequent finding among highly trained athletes, is attributed to a disproportionate increase in right cardiac work during exercise due to the smaller decrease in pulmonary resistance in relation to systemic resistance.¹⁰ Even without increased LV diastolic diameter, in 42% of athletes (42%) LV end-diastolic volume indexed to body surface area was higher than normal (61 mL/m²). However, no increase was observed when these values were indexed

Table 1 – Comparison between the athlete and control groups: demographic data, cavity dimensions, volumes, mass, and systolic and diastolic function

Parameter	Athletes (Mean ± SD)	Controls (Mean ± SD)	Z-score	P-value
Age (years)	22.14±6.29	21.24±5.02	0.6904	0.2450
Weight (kg)	60.02±6.71	65.24±6.21	3.4179	0.0003*
Height (cm)	166.05±7.98	164.24±6.48	1.0836	0.1393
Body surface (m ²)	1.67±0.13	1.69±0.09	1.1715	0.1207
Body mass index (Kg/m ²)	21.75±1.79	24.29±3.03	3.9007	< 0.0001*
HR (bpm)	62.95±9.01	75.28±8.69	5.8483	< 0.0001*
LVDD (mm)	45.82±2.25	45.12±2.62	1.1687	0.1213
DST (mm)	7.70±0.46	6.43±0.56	9.9477	< 0.0001*
DWT (mm)	7.67±0.48	6.40±0.58	9.5563	< 0.0001*
AoD (mm)	27.26±2.88	27.84±2.88	0.8344	0.2020
LAD (mm)	31.00±2.85	27.72±2.34	5.4571	< 0.0001*
RVDD (mm)	29.82±3.85	28.54±2.13	1.9342	0.0265*
IVCD (mm)	20.26±4.01	15.86±1.59	0.1320	0.4475
LV mass index (g/m ²)	68.67±8.01	54.69±8.35	7.0626	< 0.0001*
Relative thickness	0.34±0.03	0.29±0.03	1.057	0.15
LV/BS diastolic volume	59.74±10.84	51.30±9.41	13.588	< 0.0001*
LA/BS volume	21.73±5.94	20.86±5.77	3.161	0.0008*
LV ejection fraction (%)	63.45±5.99	59.57±7.55	4.5817	< 0.0001*
Mitral E wave (cm/s)	89.84±12.83	89.34±10.76	0.1818	0.4279
Mitral A wave (cm/s)	49.48±8.30	49.16±11.60	0.1227	0.4512
E/A Ratio	1.86±0.36	1.90±0.42	0.4677	0.3200
Tissue e' wave (cm/s)	18.40±2.50	18.48±1.62	0.8504	0.1976
Mean E/e' ratio	4.94±0.78	4.85±0.56	0.5692	0.2846

HR: heart rate; LVDD: left ventricular diastolic diameter; DST: diastolic septal thickness; DWT: diastolic wall thickness; AoD: aorta diameter; LAD: left atrial diameter; RVDD: right ventricular diastolic diameter; IVCD: inferior vena cava diameter; LV/BS: left ventricle/body surface; LA/BS: left atrium/body surface; *: statistically significant.

Table 2 – Comparison of myocardial strain parameters between the athlete and control groups

Parameter	Athletes (Mean ± SD)	Controls (Mean ± SD)	Z-score	P-value
LV global longitudinal strain (%)	-21.78±2.16	-21.52±2.28	0.061	0.48
LV systolic Longitudinal SR (s ⁻¹)	-1.18±0.38	-1.03±0.14	0.123	0.45
LV diastolic SR (s ⁻¹)	1.41±0.48	1.45±0.40	0.322	0.25
LV global circumferential strain (%)	-24.01±2.87	-22.97±3.20	0.051	0.48
LV global radial strain (%)	37.33±11.31	47.04±8.38	15.584	< 0.0001*
RV longitudinal strain (%)	-26.23±2.79	-28.12±3.02	2.326	0.01*
RV longitudinal SR (s ⁻¹)	-1.33±0.40	-1.18±0.16	0.223	0.41
LA basal rotation (°)	-4.63±1.83	-6.10±3.60	5.118	< 0.0001*
LA apical rotation (°)	3.66±1.68	13.10±6.00	17.227	< 0.0001*
LA twist (°)	8.30±2.43	16.10±6.40	14.570	< 0.0001*
LA longitudinal strain (%)	45.21±10.68	44.42±12.89	0.452	0.33
RA longitudinal strain (%)	41.77±10.23	40.18±13.01	0.256	0.40

LV: left ventricle; SR: strain rate; RV: right ventricle; LA: left atrium; RA: right atrium; *: statistically significant.

to height,¹¹ which seems to indicate that we are at one end of the normality curve, where a different methodology should be applied.

The LV mass index was also significantly higher in the athlete group than the control group, although remaining within normal limits, with a maximum value of 88.37 g/m² (normal value = ≤ 95 g/m²). The fact that the athlete group had a higher indexed LA volume has been reported by other authors^{7, 12} and could be related to volume overload due to the sustained increase in cardiac output during training.¹³

Regarding myocardial deformation parameters, LV radial strain was lower in the athlete group, but was still within normal range (variation from 25% to 67%). One possibility is that this parameter increases during physical exertion, which could indicate a form of contractile reserve. Other authors have found increased radial strain in male athletes.¹⁴ The lower RV longitudinal strain (varying from -19.40% to -31.90%) in the athlete group could be related to this

Table 3 – Comparison between the main and <17 athlete groups: demographic data, cavity dimensions, volumes, mass, and systolic and diastolic function

Parameter	Main group (Mean ± SD)	< 17 group (Mean ± SD)	Z-score	P-value
Age (years)	26.50±5.14	16.56±0.58	10.8571	< 0.0001*
Weight (kg)	60.44±6.70	59.48±6.83	0.5296	0.2982
Height (cm)	166.22±8.0	165.84±8.11	0.1759	0.4302
Body surface (m ²)	167.00±0.13	1.66±0.13	0.3644	0.3578
Body mass index (Kg/m ²)	21.87±1.96	21.59±1.58	0.5891	0.2779
HR (bpm)	62.69±10.82	63.28±6.18	0.2602	0.3973
LVDD (mm)	45.41±2.21	46.36±2.23	1.6063	0.0541
DST (mm)	7.97±0.18	7.36±0.49	5.9188	< 0.0001*
DWT (mm)	7.88±0.34	7.40±0.50	4.0839	< 0.0001*
AoD (mm)	27.66±3.05	26.76±2.62	1.1915	0.1167
LAD (mm)	32.47±2.17	29.12±2.52	5.2846	< 0.0001*
RVDD (mm)	31.91±3.48	27.16±2.39	6.0936	< 0.0001*
IVCD (mm)	20.55±4.41	19.44±3.43	1.0662	0.1432
LV mass index (g/m ²)	69.89±6.38	67.11±9.63	0.0144	0.4942
Relative thickness	0.35±0.02	0.32±0.02	5.1843	< 0.0001*
Diastolic volume LV/BS	58.14±9.02	61.79±12.70	0.0229	0.4909
LA/BS Volume	19.82±4.23	24.18±6.95	2.7632	0.0029*
Ejection fraction (%)	64.44±5.44	62.19±6.52	1.3879	0.0826
Mitral E wave (cm/s)	86.65±13.01	93.92±11.60	2.2257	0.0130*
Mitral A wave (cm/s)	51.25±9.29	47.21±6.30	1.9545	0.0253*
E/A ratio	1.73±0.37	2.01±0.30	3.1641	0.0008*
e' tissue wave (cm/s)	17.98±2.40	18.93±2.57	1.4260	0.0769
Mean E/e' ratio	4.88±0.88	5.01±0.62	0.6385	0.2616

HR: heart rate; LVDD: left ventricular diastolic diameter; DST: diastolic septal thickness; DWT: diastolic wall thickness; AoD: aorta diameter; LAD: left atrial diameter; RVDD: right ventricular diastolic diameter; IVCD: inferior vena cava diameter; LV/BS: left ventricle/body surface; LA/BS: left atrium/body surface; *: statistically significant.

Table 4 – Comparison of myocardial deformation parameters between the main and under-17 athlete groups

Parameter	Main group (Mean ± SD)	< 17 group (Mean ± SD)	Z-score	P-value
LV global longitudinal strain (%)	-21.58±2.56	-22.03±1.52	0.8379	0.2010
LV longitudinal systolic SR (s-1)	-1.00±0.10	-1.40±0.48	4.1393	< 0.0001*
LV diastolic SR (s-1)	1.19±0.15	1.69±0.60	4.0869	< 0.0001*
LV global circumferential strain (%)	-23.66±2.79	-24.46±2.97	1.0359	0.1501
LV global radial strain (%)	32.91±5.32	43.00±14.22	3.3697	0.0004*
RV longitudinal strain (%)	-26.38±3.04	-26.03±2.48	0.4727	0.3182
RV longitudinal SR (s-1)	-1.18±0.13	-1.51±0.54	2.9423	0.0016*
LV basal rotation (°)	-4.72±2.00	-4.51±1.62	0.4337	0.3322
LV apical rotation (°)	3.05±1.37	4.45±1.75	3.2836	0.0005*
LV twist (°)	7.78±2.45	8.96±2.28	1.8871	0.0296*
LA longitudinal strain (%)	46.31±11.39	43.80±9.74	0.8969	0.1849
RA longitudinal strain (%)	43.08±10.78	40.10±9.41	1.1102	0.1335

LV: left ventricle; SR: strain rate; RV: right ventricle; LA: left atrium; RA: right atrium; *: statistically significant.

cavity's larger dimensions, with increased end-systolic parietal stress, proportionally much greater than what the LV undergoes during effort. The increase in parietal stress was estimated at 125% for the RV and 14% for the LV.¹⁵ The RV strain rate, however, did not decrease, suggesting that the chamber's longitudinal function is preserved.

The subject of rotational deformation is controversial. In our sample of athletes, all parameters were decreased (basal rotation, apical rotation, and twist). Some authors report that these indices are higher in athletes,^{14,16} while others report a decrease in rotational mechanics, especially among athletes with a high aerobic and low anaerobic load.^{17,18} Nevertheless, we hypothesize that, in addition to LV radial strain, rotational mechanics increase considerably during physical exertion, representing a form of contractile reserve.¹⁹ Performing echocardiographic examinations during training, other authors have found that all rotational parameters gradually increase during exercise in proportion to exercise intensity.²⁰

Our study was based on the assumptions that all of the athletes on the national team began playing on the junior teams and were subsequently promoted, undergoing the same type of intensive training prior to 17 years of age, as well as that the younger athletes would have different levels of adaptation from those on the main team, due to their greater age and training experience.

Comparing the athletes by career length (ie, main vs < 17 groups), significant differences were found in age, weight, height, body surface area, and body mass index. The main group had a smaller LV diastolic diameter and greater relative and end-diastolic thickness of the interventricular septum and free posterior wall. This seems to indicate adaptive concentric remodeling that remained within normal limits.

Indexed LA volume and RV size were also greater in the main group for the same reasons, ie, a sustained increase in LA cardiac output and lower reduction in RV pulmonary resistance.

Controlled studies in high-performance athletes involved in submaximal and supramaximal training found no increase in LV dimensions, although the diameter and indexed volume of the LA were increased.²¹

Some authors have reported that, due to disproportionate work during intense exercise, decompensation and a greater predisposition to arrhythmias occur in the RV.²²

Among the diastolic function parameters in the main group, the mitral E wave velocity was lower, the A wave velocity higher, and the E/A ratio was lower. No differences were found regarding velocity in tissue Doppler imaging or the E/e' ratio. These data might be related to age-based physiological changes in the main group, although they had normal ventricular filling pressure.

The most interesting differences were in myocardial deformation. In longitudinal mechanics, although LV global longitudinal strain did not significantly differ, the systolic strain rate and the early diastolic strain rate were significantly higher in the < 17 group, suggesting greater efficiency in longitudinal strain and ventricular filling among younger athletes. Circumferential strain did not differ significantly between the groups.

Radial strain was higher in the < 17 group, suggesting greater efficiency or even decrease in older athletes, indicating better contractile reserve. RV longitudinal strain did not differ significantly between groups but, again, the RV strain rate was higher in the < 17 group.

Regarding rotational deformation, both the main and < 17 groups had decreased basal rotation, with no significant difference between groups, although the values were lower than those of the control group. Apical rotation, which was also lower among athletes than controls, was significantly lower in the main group, as was twisting. Reduced apical

rotation and twisting at rest may indicate greater contractile reserve acquired through longer training, as has been reported by some authors, who found values similar to those of the present study.¹⁹

Conclusions

Compared to sedentary women in the same age group, elite female soccer athletes were thinner and had a lower heart rate.

There was a trend toward eccentric remodeling, greater RV diameter, LA diameter and indexed volume, and LV ejection fraction, although they were within normal limits. Myocardial deformation parameters showed lower LV radial strain, RV longitudinal strain, and rotational parameters (basal, apical, and twisting rotation).

Compared to the < 17 group, athletes from the main group had a smaller LV diameter, greater relative and parietal thickness, and tended to have concentric adaptation. The greater LA and RV dimensions in the main group of athletes, as well as the lower apical rotation and twisting, may correspond to a greater contractile reserve acquired through longer training.

Author contributions

Conception and design of the research: Castillo JMD, Boschilia T, Sabeh Júnior N, Silveira CAM; acquisition of data: Castillo JMD, Boschilia T, Sabeh Júnior N, Silveira CAM; analysis and interpretation of the data: Castillo JMD, Boschilia T, Sabeh Júnior N, Silveira CAM; statistical analysis: Castillo JMD, Boschilia T, Sabeh Júnior N, Silveira CAM; writing of the manuscript: Castillo JMD, Boschilia T, Sabeh Júnior N, Silveira CAM; critical revision of the manuscript for intellectual content: Castillo JMD, Boschilia T, Sabeh Júnior N, Silveira CAM; Brindeiro Filho D.

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This article does not contain any studies with human participants or animals performed by any of the authors.

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