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Doppler echocardiography in athletes from different sports

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Background: Studies have shown cardiac changes induced by intense and regular physical activity. The purpose of this study was to evaluate cardiac structures and function in soccer players, cyclists and long-distance runners, and compare them with non-athlete controls.

Material/Methods: Cardiac structural, systolic, and diastolic function parameters in 53 athletes and 36 non-athlete controls were evaluated by Doppler echocardiography.

Results: Athletes presented higher left atrial volume, left ventricular (LV) thickness, and LV and right ventricular (RV) diastolic diameters (LVDD and RVDD, respectively) compared to non-athletes. Left atrium and LVDD were higher in cyclists than runners, and RVDD was higher in cyclists than soccer players. LV mass index was higher in athletes, and cyclists had higher values than runners and soccer players. LV systolic function did not differ significantly between groups. The only altered index of LV diastolic function was a higher E/A ratio in cyclists compared to controls. There was no difference in LV E/E' ratio. RV systolic function evaluated by tissue Doppler imaging was higher in cyclists and soccer players than runners. There were no conclusive differences in RV diastolic function.

Conclusions: Soccer players, runners and cyclists had remodeling of left and right ventricular structures compared to controls. Cardiac remodeling was more intense in cyclists than runners and soccer players.

Key words: **athlete's heart • athlete's Doppler echocardiography • ventricular remodeling • cycling • soccer • long-distance running**

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Background

The expression "athlete's heart" is usually used to characterize cardiovascular effects of long-term exercise in competitive and highly trained athletes [1]. Prolonged intensive physical training causes cardiovascular adaptations that are responsible for supernormal performance. However, the significance of anatomical and functional modifications caused by physical exercise, often beyond normal limits, remains controversial. Physical exercise is a stimulating factor in the development of left ventricular hypertrophy, which is modulated by sport characteristics [2,3]. This hypertrophy is considered a physiological and benign adaptation to systematic training, and is not associated with adverse cardiovascular consequences [4]. Several echocardiographic studies have shown that physical training is associated with left ventricular cavity enlargement and increased mass and wall thickness [5–16]. Despite several studies showing cardiac adaptations induced by exercise, left and right ventricular adaptation in soccer players, cyclists, and long-distance runners has not been completely established. The aim of this study was to investigate cardiac structures and function in athletes from sports with different strength and endurance levels. We evaluated athletes from soccer, cycling, and long-distance running and compared the results with non-athlete controls. Long-distance runners are characterized by endurance training, but soccer and cycling athletes are characterized by mixed strength/endurance training. The study was accomplished using echocardiogram, a non-invasive imaging exam, which is the main source of obtaining information on cardiac adaptation in response to intensive training in athletes [12,17–19].

Material and Methods

Subjects

The study included 57 male competitive athletes from 3 different sports (21 soccer players, 19 long-distance runners, and 17 cyclists), aged 32.9±8.4 years, and 36 non-athlete male controls with similar anthropometric measurements and age (30.4±11.1 years). The project was approved by the Research Ethics Committee of Marilia School of Medicine (Sao Paulo state, Brazil). Written informed consent was obtained from all participants.

The runners were members of the Marilia Runners Association, the cyclists were professionals affiliated with the Marilia and Assis cycling teams, and the soccer players were professionals from the Marilia Athletic Football Club. The runners took part in marathons and 10, 15, and 21 km races. They trained approximately 2 to 3 hours per day (6 times per week), for a total of 80 to 120 km per week, and could complete a marathon in 3 hours. The cyclists were competing at national and international levels. Their main competitions were the national Round Sao Paulo State Race and the Open Inland Sao Paulo State Games; they also participated in competitions around the countryside of Sao Paulo and Parana states; all of these races were long-distance (more than 1000 km over several days). The cyclists trained about 24 hours per week, or 600 km of training over 6 days, and did not undertake any other training during the year, except for a short period of preseason weightlifting. Soccer players' training sessions included isotonic and isometric exercises totaling approximately 26 hours per week. Players from all positions were studied, except goalkeepers who underwent a different training routine. All athletes were at their peak performance level at the time of exams. The control group was composed of healthy males not involved in regular physical activity.

Echocardiography

All echocardiograms were performed by the same examiner at Marilia Cardiology Institute's Echocardiography Unit (Brazil) [20–22]. The echocardiograph was an Envisor C model (Philips Medical Systems, Andover, Massachusetts, USA), equipped with a 2.0–4.0 MHz probe capable of acquiring second harmonic, tissue, pulsed, continuous, and color Doppler, as well as 1- and 2-dimensional mode images. With individuals positioned in left lateral decubitus position and monitored with an electrocardiographic lead, the following echocardiographic cuts were performed: short parasternal axis to measure ventricles, aorta and left atrium; apical 2, 4 and 5 chambers to evaluate cavities and systolic and diastolic functions of ventricles. All measurements were performed in accordance with American Society of Echocardiography recommendations [23]. The average of 3 measurements was calculated for each variable.

Left ventricular (LV) mass (LVM) was calculated according to the Devereux formula [24]:

$$\mathrm{LVM}=0.8\times\{1.04\times[(\mathrm{LVDD}+\mathrm{IVSDT}+\mathrm{PWDT})^3-\mathrm{LVDD}^3]\}+0.6,$$

where LVDD, IVSDT, and PWDT represent LV diastolic diameter, interventricular septum diastolic thickness, and posterior wall diastolic thickness, respectively. Left atrium volume was obtained by the Simpson's method from apical 2- and 4-chamber views. LV systolic function was evaluated by measuring the ejection fraction according to the Simpson and Teicholz method [25], endocardial fractional shortening, Tei index [26], and systolic velocity of mitral annulus (average of anterior, septal, inferior, and lateral walls). LV diastolic function was evaluated by measuring early (E wave) and late (A wave) diastolic mitral inflow velocity, their ratio, E wave deceleration time (EDT), isovolumic relaxation time (IVRT), early (E' wave) and late (A' wave) diastolic mitral annulus velocity

Table 1. General characteristics of athletes and non-athlete controls.

Parameters	Control (n=36)	Soccer players (n=21)	Runners (n=19)	Cyclists (n=17)
Age (years)	30.0 (27.0–35.0)	22.0 (20.0–23.0)*	43.0 (35.7–50.7)†	26.0 (23.0–28.2)$^{\#}$
Weight (kg)	77.1±1.5	75.8±1.5	65.4±1.5*,†	67.7±1.76*,†
Height (m)	1.80±0.01	1.77±0.01	1.73±0.01*	1.74±0.01*
BMI (kg/m^2)	23.8±0.33	24.3±0.41	21.9±0.45*,†	22.3±0.43†
BSA (m^2)	1.95±0.03	1.92±0.02	1.78±0.02*,†	1.81±0.03*,†
HR (bpm)	68.4±9.31	56.5±4.92*	55.3±9.18*	55.5±6.50*
SAP (mmHg)	120.0 (110–130)	120.0 (110–130)	110.0 (100–120)*	113.0 (100–120)
DAP (mmHg)	80.0 (77.5–80.0)	80.0 (73.7–85.0)	70.0 (66.2–80.0)	80.0 (65.0–80.0)

Values are mean ±SEM or median and 25th and 75th percentile. kg – kilograms; m – meters; mmHg – milimeters of mercury; BMI – body mass index; BSA – body surface area; HR – resting heart rate; bpm – beats per minute; SAP – systolic blood pressure; DAP – diastolic blood pressure. $^{*,\dagger,\#}$ p<0.05 *vs.* control, soccer players and runners, respectively (ANOVA and Tukey; Kruskal-Wallis and Dunn).

(average of anterior, septal, inferior, and lateral walls) by tissue Doppler, and E/E' ratio.

The right ventricle (RV) was structurally evaluated by measuring diastolic and systolic diameters and areas. RV systolic function was evaluated by calculating fractional area change and measuring systolic tricuspid annulus velocity. RV diastolic function was assessed by measuring tricuspid E and A waves and their ratio, EDT, IVRT, E' and A' waves, and the E/E' ratio.

Statistical analysis

General characteristics between groups were compared by analysis of variance (ANOVA) followed by the Tukey test when distribution was normal, and ANOVA on ranks (Kruskal-Wallis) followed by the Dunn test when the distribution was non-normal. Echocardiographic variables were compared by analysis of covariance (ANCOVA), using age as the covariant, complemented by the Tukey test. SYSTAT 12 statistical software for Windows (SYSTAT Software, Inc., USA) was used. Statistical significance was accepted at the level of P<0.05.

Results

Table 1 shows the general characteristics of athletes and non-athlete controls. Runners were statistically older than soccer players and cyclists, and soccer players were younger than controls. Body weight was lower in runners and cyclists than soccer players and controls. Height was significantly lower in runners and cyclists than in non-athletes. Body mass index was lower in runners and cyclists than soccer players, and also in runners compared to controls. Body surface area was also significantly lower in runners and cyclists than in soccer players and controls. Diastolic arterial pressure values did not differ between groups, whereas systolic arterial pressure was slightly lower in runners than in non-athletes.

LV structural evaluation (Table 2) shows that cyclists and soccer players presented greater diastolic and systolic diameters than controls. Furthermore, cyclists presented greater diastolic diameter than runners. Diastolic LV wall thickness (IVSDT and PWDT) were increased in the 3 athlete groups compared to controls. LV mass was higher in athletes than controls, and higher in cyclists than runners. LV mass index was significantly higher in athletes, and cyclists showed higher values compared to soccer players and runners. Aortic diameter was similar between groups. Left atrium (LA) volume and LA volume index were greater in athletes than controls. LA volume was also greater in cyclists than runners, and LA volume index was higher in cyclists than soccer players.

Left ventricular systolic function was not different between groups. Tei index, a systo-diastolic index, also showed no difference between groups (Table 3). In relation to LV diastolic function (Table 4), mitral E and A waves, and EDT were similar between groups. E/A ratio was significantly higher in cyclists than controls. IVRT was higher in runners than controls and soccer players. A' wave was lower in runners than controls. E' wave and E/E'ratio were not different between groups.

Right ventricular diastolic and systolic diameters and areas were significantly greater in athlete groups than controls. Furthermore, the cyclists presented higher diastolic diameter and area than soccer players (Table 5). RV systolic function evaluated by tissue Doppler (S wave) was significantly decreased

Table 2. Structural parameters of left ventricle, left atrium and aorta.

Parameters	Control (n=36)	Soccer players (n=21)	Runners (n=19)	Cyclists (n=17)
LVDD (mm)	49.6±0.49	53.8±0.71*	51.2±0.77	55.6±0.72$^{*,\#}$
LVSD (mm)	31.3±0.51	34.7±0.71*	33.2±0.81	35.8±0.76*
IVSDT (mm)	8.53±0.17	10.5±0.24*	9.80±0.26*	10.5±0.24*
PWDT (mm)	8.40±0.22	10.5±0.32*	9.82±0.35*	10.5±0.33*
AOD (mm)	32.5±0.54	32.1±0.79	32.5±0.86	32.8±0.80
LAD (mm)	35.1±0.51	38.3±0.74*	35.6±0.80	39.6±0.75$^{*,\#}$
LAV (ml)	42.7±1.66	56.1±2.42*	52.3±2.68*	62.8±2.45$^{*,\#}$
LAVI (ml/m^2)	22.0±0.81	28.8±1.19*	30.1±1.32*	34.5±1.20*,†
LVM (g)	144±5.4	214±8.0*	184 ±8.6*	231±8.1$^{*,\#}$
LVMI (g/m^2)	74.1±2.8	110±4.0*	105±4.4*	128±4.1$^{*,\dagger,\#}$

Values are mean ±SEM. LVDD – left ventricular diastolic diameter; DSVE – left ventricular systolic diameter; IVSDT – interventricular septum diastolic thickness; PWDT – posterior wall diastolic thickness; AOD – aortic diameter; LAD – left atrial diameter; LAV – left atrial volume; LAVI – left atrial volume index; LVM – left ventricular mass; LVMI – left ventricular mass index. $^{*,\dagger,\#}$ p<0.05 *vs.* control, soccer players and runners, respectively (ANCOVA and Tukey).

Table 3. Left ventricular systolic function.

Parameters	Control (n=36)	Soccer players (n=21)	Runners (n=19)	Cyclists (n=17)
EF (Teicholz)	0.66±0.01	0.64±0.01	0.64±0.01	0.64±0.01
EF (Simpson)	0.53±0.01	0.54±0.01	0.53±0.01	0.52±0.01
FS (%)	36.4±0.62	35.5±0.91	34.8±0.98	35.5±0.92
Tei index	0.52±0.02	0.65±0.04	0.57±0.04	0.58±0.04
Tissue S wave (cm/s)	11.8 ±0.33	11.4±0.48	10.3±0.52	11.7±0.49

Values are mean ±SEM. EF – ejection fraction; FS – endocardial fractional shortening; S wave – systolic mitral annulus velocity (average of anterior, septal, inferior, and lateral walls); p>0.05 (ANCOVA).

in runners than other athletes. RV diastolic function differed significantly only in IVRT evaluated by tissue Doppler, which was greater in runners than controls (Table 5).

Discussion

In this study we evaluated cardiac remodeling caused by different types of intense physical activity. Athlete's heart involves a series of morphological and functional alterations resulting from vigorous and systematic physical training.

Cardiac adaptations depend on exercise classification, which can be divided into 2 types: dynamic (also called resistance, aerobic or isotonic exercise), and static (otherwise known as strength, anaerobic or isometric exercise) [27]. The majority of sports are not purely static or dynamic, but rather a mixture of both, and are considered to be mixed exercise.

Physiological changes resulting from dynamic exercise are seen in athletes who practice sports requiring long-term, medium to high intensity, physical activity. This exercise causes a marked increase of heart rate and cardiac output and a slight increase in arterial pressure. For instance, arterial pressure increases slightly in endurance athletes, and cardiac output of 5 to 6 liters per minute at rest can reach as much as 40 liters per minute at peak exertion [13]. These athletes display eccentric left ventricular hypertrophy [28]. In contrast to dynamic exercise,

Table 4. Left ventricular diastolic function.

Parameters	Control (n=36)	Soccer players (n=21)	Runners (n=19)	Cyclists (n=17)
E wave (cm/s)	74.7±2.2	83.3±3.2	79.1±3.4	80.6±3.2
A wave (cm/s)	49.6±1.52	50.0±2.2	45.3±2.4	46.0±2.2
E/A ratio	1.52±0.05	1.75±0.07	1.70±0.08	1.84±0.07*
IVRT (ms)	97.6±1.43	97.4±2.1	109±2.3*,†	101±2.1
EDT (ms)	169±4.6	176±4.6	187±7.3	170±6.8
E’ wave (cm/s)	16.6±0.35	17.3±0.52	16.8±0.56	17.4±0.52
A’ wave (cm/s)	9.61±0.25	8.57±0.37	7.66±0.40*	8.62±0.38
E/E’ ratio	4.53±0.14	4.84±0.21	4.71±0.12	4.50±0.11

Values are mean ±SEM. E wave – early diastolic mitral inflow velocity; A wave – late diastolic mitral inflow velocity; IVRT – isovolumic relaxation time; EDT – E wave deceleration time; E’ wave – early diastolic mitral annulus velocity (average of anterior, inferior, septal, and lateral walls); A’ wave – late diastolic mitral annulus velocity (average of anterior, inferior, septal, and lateral walls); *, † p<0.05 *vs.* control and soccer players, respectively (ANCOVA and Tukey).

Table 5. Right ventricular structural and functional parameters.

Parameters	Control (n=36)	Soccer players (n=21)	Runners (n=19)	Cyclists (n=17)
RVDD (mm)	24.2±0.37	26.7±0.55*	28.6±0.59*	30.8±0.55*,†
RVSD (mm)	16.8±0.39	18.1±0.55*	20.4±0.60*	21.3±0.56*
Diast. RV area (cm²)	35.3±1.97	49.0±2.88*	52.1±3.12*	60.4±2.92*,†
Syst. RV area (cm²)	18.4±1.28	26.6±1.87*	26.6±1.87*	32.1±1.87*
Tissue S wave (cm/s)	13.7±0.47	15.4±0.68	11.8±0.74†	14.9±0.69#
Tei index	0.34±0.02	0.38±0.03	0.34±0.04	0.38±0.03
Fractional area change	48±2.0	44±3.0	48±3.0	46±3.0
E wave (cm/s)	51.3±1.7	49.6±2.6	47.8±2.8	51.4±2.6
A wave (cm/s)	29.0±0.9	28.3±1.4	26.6±1.5	28.0±1.4
E/A ratio	1.78±0.04	1.77±0.06	1.80±0.06	1.88±0.06
IVRT (ms)	94.6±1.54	96.3±2.26	102±2.44*	99.1±2.28
EDT (ms)	192±6.2	182±9.0	185±9.8	178±9.1
E’ wave (cm/s)	14.2±0.81	13.2±1.18	13.9±1.28	15.6±1.20
A’ wave (cm/s)	1.3±0.56	10.4±0.82	9.80±0.89	11.4±0.83
E/E’ ratio	3.74±0.16	3.68±0.24	3.71±0.26	3.78±0.24

Values are mean ±SEM. RVDD – right ventricular diastolic diameter; diast. – diastolic; syst. – systolic; S wave – systolic tricuspid annulus displacement; E wave – early diastolic tricuspid inflow velocity; A wave – late diastolic tricuspid inflow velocity; IVRT – isovolumic relaxation time; EDT – E wave deceleration time; E’ wave – early diastolic tricuspid annulus velocity; A’ wave – late diastolic tricuspid annulus velocity; *, †, # p<0.05 *vs.* control, soccer players and runners, respectively (ANCOVA and Tukey).

cardiac alterations caused by static exercise can be seen in athletes performing highly intense short-term types of physical exercise. In this case, a mild increase in heart rate and cardiac output is observed, while arterial pressure substantially increases. In sports such as weightlifting there are reports of blood pressure rising to 480/350 mmHg [29]. Consequently, a concentric type of left ventricular hypertrophy develops [28]. In fact, a recent study by D'Andrea et al [16] showed increased sum of wall thickness and increased relative wall thickness in strength-trained athletes compared to endurance-trained athletes. However, the practice of mixed exercises is observed in most sports, characterized by long-term moderate or high intensity physical activity. In this type of exercise, a prolonged substantial increase in cardiac output and heart rate and a moderate increase in systolic arterial pressure are observed. In this case, mixed or balanced left ventricular hypertrophy occurs [28].

In our study, soccer players and cyclists presented larger diastolic and systolic LV diameters than non-athlete controls. Also, LV diastolic wall thickness was higher in athletes. Consequently, LV mass was significantly higher in athletes than controls. These data are similar to those found in several studies on athletes from different sports [7,8,14,28,30–32]. LA volume and volume index were increased in all athlete groups. Mild LA volume index enlargement was observed in 24.3% in a large population of highly trained athletes [33]. In our study, LA volume was greater in cyclists than runners, and LA volume index was higher in cyclists than soccer players. This alteration can be explained by the type of physical activity, with combined dynamic and static exercise, mainly in cyclists, resulting in the greatest LA enlargement. This result is in accordance with the study by Pellicia et al. [34] who, in 1777 competitive athletes, found that LA dimension was closely related to type of sport, with cycling, rowing, and canoeing producing the greatest impact.

We evaluated LV systolic function by examining ejection fraction using Teicholz and bi-planar Simpson methods, endocardial fractional shortening, myocardial performance index, and tissular systolic wave. We did not find any differences between groups, thus corroborating data from the literature [8,10,14,15,17,30–32,35–37]. For LV diastolic function, there was no difference in E wave, A wave, or EDT between groups. The E/A ratio was significantly higher in cyclists than controls. Previous studies have shown an increased E/A ratio in endurance-trained compared with strength-trained athletes [3,33]. E' wave did not differ between groups, whereas A' wave was slower in runners than non-athletes. The E/E' ratio did not statistically differ between groups. We can speculate that cyclists present supernormal LV diastolic function.

Studies have shown that hemodynamic overload in athletes during physical activity causes LV and RV dilatation [37–41]. Athletes in this study demonstrated increases in RV systolic and diastolic diameters and areas compared to controls; we also observed a significant increase in RV diastolic diameter and area for cyclists compared to soccer players. Assessment of RV systolic function is challenging due to complex geometry, poor endocardial definition, and the low accuracy seen in 2-dimensional echocardiography [23,42–45]. The only difference seen in the many indexes was for systolic tricuspid annulus velocity, which was lower in runners than the other athletes. This tissue Doppler index evaluates right ventricular function in a quick, simple manner, giving a high sensitivity and specificity comparable to nuclear magnetic resonance and radionuclide ventriculography [44]. We studied RV diastolic function by analyzing transtricuspid flow velocity and diastolic tricuspid annulus velocity. Isovolumetric relaxation time was the only index where we found a difference, being significantly higher in runners than controls and soccer players. Because runners were older than soccer players, we cannot discount the potential impact of age on decreased systolic tricuspid annulus velocity and increased isovolumetric relaxation time in runners compared to soccer players.

Conclusions

In conclusion, soccer players, runners, and cyclists present cardiac remodeling characterized by LV hypertrophy and LV, left atrium, and right ventricle dilatation. Cardiac remodeling is more intense in cyclists than runners and soccer players; cyclists present a supernormal pattern of LV diastolic function in relation to non-athletes. Athletes present systolic LV function similar to controls. No conclusive difference could be found in relation to right ventricular systolic and diastolic function.

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Conflict of interest

There are no conflicts of interest in this study.

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