Left Ventricular Hypertrophy of Athletes. Adaptative Physiologic Response of the Heart

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Objective

To verify whether left ventricular hypertrophy (LVH) of elite competition athletes (marathoners) represents a purely physiological, adaptative process, or it may involve pathological aspects in its anatomical and functional characteristics.

Methods

From November 1999 to December 2000, consecutive samples from 30 under 50-year-old marathoners in full sportive activity, with previously documented LVH and absence of cardiopathy were selected. They were submitted to clinical exams, electrocardiogram, color Doppler echocardiogram and exercise treadmill test (ETT). Fifteen were assorted to be also submitted to ergoespirometric test and heart magnetic resonance imaging (MRI).

Results

In ETT, all of them showed good physical pulmonary capacity, with no evidences of ischemic response to exercise, symptoms or arrhythmias. In Doppler echocardiogram, values of diameter and diastolic thickness of LV posterior wall, interventricular septum, LV mass and left atrium diameter, were significantly higher when compared to non-athlete control group, with similar ages and anthropometric measurements. The mean of LV mass of athletes indexed to body surface (126 g/m2) was significantly greater than the one in control group (70 g/m2) ($p<0.001$). Magnetic resonance imaging (MRI) showed there was not impairment of contractile strength or LV performance, and values of end diastolic volume, end systolic volume and EF within limits of normality. On the other hand, average ventricular parietal mass, 162.93±17.90 g, and LV parietal thickness, 13.67±2.13 mm, at the end of diastole in athlete group, differed significantly from control group: 110±14.2 g ($p=0.0001$) and 8±0.9 mm, respectively ($p=0.0001$). The same happened to the thickness at the end of systole, which was 18.87±3.40 mm (control group: 10±1.80 mm, $p=0.0001$).

Conclusion

Results allowed for concluding that LVH in marathoners in full sportive activity period, assessed by non-invasive methods, represents an adaptative response to intensive and prolonged physical training, with purely physiological characteristics.

Key words

cardiac hypertrophy, athletic heart, athletic cardiomegaly

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Cardiac hypertrophy of highly trained athletes has been acknowledged for more than a century by Bergmann (1884) and Parrot (1893), mentioned by Rost[1], and consists of one of the most frequent findings in athletic hearts.

However, controversies still persist on its real meaning. Would it be about a purely physiological process, compensatory or adaptative hypertrophy, necessary to keep excellent cardiac performance under increased circulatory overload conditions, or would involve the potential of inducing, in long term, pathological changes, related to myocardial structure and compromising of cardiac performance? Most authors support the first hypothesis[1-5]. Elsewhere, some authors have questioned that point of view, by acknowledging that left ventricular hypertrophy in athletes may have pathological consequences, considering that, very often, emphatically increased values of parietal thickness and ventricular dilatation superimpose those of hypertrophic or dilated cardiomyopathy[6].

Intensive and prolonged physical training induces to cardiovascular adjustments that allow for an exceptional physical performance of athletic heart[7-9]. However, those adjustments include functional and anatomical changes that may be placed out of normality limits and whose clinical and prognostic meanings have been a matter of intense discussion and controversies[1,6].

There are many well-known cardiovascular effects of energetic physical training, which is done throughout long periods of time, experimentally observed and in highly-trained competitive athletes[2,10,11]. It is also verified a higher mechanical efficiency of skeleton musculature, increase in capillarization, enzyme activities, increase of pulmonary function capacity and a better ventilation/perfusion rate. Those cardiovascular changes result from a complex interaction of central and peripheral mechanisms, operating in structural, electrophysiological, biochemical, metabolic and neurogenic levels[12]. They depend on the intensity and length of training, type of athletic activity and genetic factors.

METHODS

In the period from November 1999 to December 2000, 306 athletes were seen, routinely sent by their respective sports entities, for pre-participation cardiologic assessment. From those, we consecutively selected 30 athletes, being eighteen whites, eleven blacks and one Far Eastern athlete, who fulfilled all inclusion criteria: male sex, age under 50 years old (ages varied from 24 to 48 years old, mean of 37.5±6.21); high endurance aerobic sports performers (marathoners) for more than three years and in a full athletic activity period; left ventricular hypertrophy at color two-dimensional Doppler echocardiogram (left ventricular thickness and mass over normality limits); absence of subjacent cardiovascular disease. From those 30 athletes, 15 were randomly selected to submit to heart magnetic resonance imaging (MRI).

The protocol of Seção Médica de Cardiologia do Esporte (Sports Cardiology Medical Section) do Instituto Dante Pazzanese de Cardiologia, do Estado de São Paulo was followed: clinical interview, with special attention to cardiovascular symptoms and signs, at rest or exercise-induced, training duration, intensity and frequency, electrocardiogram at rest[13], exercise treadmill test on treadmill, by using Bruce's protocol[14], even limiting symptom or sign, and cardiopulmonary or ergoespirometric test, with incline protocol standardized for athletes, in the 15 selected athletes submitted to heart magnetic resonance imaging. Records from color Doppler echocardiogram from 30 athletes were carried out under rest conditions and without medication administration. Each exam consisted of M-mode, two-dimensional, pulse and continuous Doppler mode assessments and through color flow mapping modalities[15,16].

Through magnetic resonance imaging (MRI), myocardial mass was quantified, cardiac fiber contraction was analyzed, and global ventricular function and left ventricular regional contractility was assessed, through tagging[17]. Such analysis is subjective and determines whether there are regional contractility defects, by comparing athletes' hearts with those of normal population. The sequence used was cine magnetic resonance imaging "FIESTA" with apnea. Definition of ventricular rims and determination of ventricular volumes were carried out at computer-aided workstation itself, dedicated to that purpose, with the manufacturer's program.

Results obtained in the group of athletes were compared with those observed in control group of 30 normal sedentary individuals, with similar anthropometric characteristics.

RESULTS

None of the 30 athletes showed clinical history of family diseases or sudden death, or personal history of clinical importance. The physical exams did not show significant abnormalities.

Electrocardiogram (ECG) assessment showed ordinary patterns among trained athletes: a) heart rate varied from 40 to 64 bpm, mean of 50.4 bpm±7.0; b) sinus bradycardia (lower than 60 bpm) in 26 athletes (87%); c) 1st degree atrioventricular block (AVB) in five cases (17%). In one, 2nd degree, Mobitz 1-type, intermittent AVB; d) right bundle branch conduction disturbance in 11 cases (37%), one of which with complete right bundle branch block, intermittent (QRS>12 mm); e) left atrial overload in six cases (20%); f) left ventricular hypertrophy[18] in eight cases (27%); g) early ventricular repolarization pattern in 19 cases (63%), juvenile pattern, in five (17%), and negative/flattened T waves (anterior wall), in two cases (7%).

Results obtained in 30 exercise treadmill test are shown in table I and the results from 15 cardiopulmonary tests are displayed in table II.

In exercise treadmill and cardiopulmonary tests, clinical and electrocardiographic parameters, observed and recorded during and after them, were considered as compatible with normality. In no case there was ischemic response to exercise, and no clinical symptoms, arrhythmias, abnormal behavior of heart rate or ventricular function were observed. The reasons for interruption of exercise in all cases was physical exhaustion that usually happened close to maximum forecast HR. Cardiorespiratory capacity of the 30 athletes was considered as "well-conditioned" functional level, higher than those found in normal sedentary individuals[19].

Doppler echocardiogram – Absolute values and values indexed to body mass and compared to control group of 30 non-athletes, with similar ages and anthropometric measurements were obtained (tables III and IV).

The means of left atrium diameter, LV systolic diameter, interventricular septum and LV posterior wall diastolic thicknesses, ventricular mass, ejection fraction and shortening percentage were significantly higher ($p<0.001$) in athlete group, in comparison with control group (tab. III).

Those same body surface-indexed variables were also significantly higher in athlete group (tab. IV).

Specifically, the mean of left ventricular mass (LVM) of athletes, indexed to body mass (126 g/m^2), was significantly greater than the one of control group (70 g/m^2) ($p<0.001$). The mean of left ventricular function, assessed through ejection fraction, was also significantly greater in athlete group (0.70) when compared to the one of control group (0.60) ($p<0.001$). LV diastolic function variables were normal among all athletes.

Magnetic resonance imaging (MRI) – Results from 15 athletes showed values of end diastolic volume, end systolic volume and ejection fraction within the limits of normality.

The comparison of results found in athletes with values from 30 normal controls (tables V and VI) did not reveal any significant difference concerning end diastolic volume ($p=0.7$), end systolic volume ($p=0.14$) and ejection fraction ($p=0.20$). On the other hand, there was a significant difference in left ventricular mass and ventricular thicknesses, at the end of diastole and systole. So, the average mass defined by magnetic resonance imaging was 162.93 ± 17.90 g in athlete group against 110 ± 14.2 g, in control group ($p=0.0001$); the mean of thickness at the end of diastole was 13.67 ± 2.13 mm in athlete group and 8 ± 0.9 mm, in control group ($p=0.0001$); and the mean of thickness at the end of systole was 18.87 ± 3.40 mm among athletes versus 10 ± 1.80 mm, in control individuals ($p=0.0001$).

Despite the magnitude of changes found, there was not dyssynergy in any case, nor impairment of ventricular performance, which was confirmed not only through global ejection fraction quantification, but also due to the fact that left ventricular regional movement, assessed through tagging, did not show significant changes in any of the cases. Regional thickening measurement of all assessed athletes was found within normality limits and diastolic function of athletes was shown, similarly, normal with discreet changes, without clinical meaning (tab. VII).

Discussion

Athletic heart shows a variety of morphological and functional changes, resulting from demanding and systematic physical training, to improve heart function as a pump and the ability of cardiovascular system to supply oxygen to muscles under exercise. Prevailing adjustments include: increase of end diastolic dimension of left ventricular cavity, of parietal thickness and of left ventricular mass, improvement of diastolic filling and heart rate reduction.

Left ventricular hypertrophy develops was a compensatory or adaptative process to a hemodynamic stimulus, representing pressure and/or volume overload. The theory, which best describes hypertrophy patterns, takes into consideration that ventricular response is processed in a way to maintain ventricular parietal stress relatively constant and the suitable systolic volume.

Physical exercise is a well-identified stimulus for left ventricular hypertrophy development. Structural changes, resulting from physical training, depend on nature, duration and intensity of the exercise. Many sports have been fundamentally classified in two big groups: endurance sports, in which isotonic or dynamic forms of exercise prevail, and strength sports, in which isometric or static forms of exercise prevail. However, athletic conditioning is rarely purely isotonic or isometric. Most physical activities involve a dynamic and static component, although with preponderance of one of them[8,20-22].

Another relevant aspect is that exercise-associated overload probably represents the primary mechanism responsible for cardiac structure changes. In animal models[23], it has been observed that myocardial hypertrophy had a very close relation with hemodynamic overload intensity, whereas plasma and cardiac catecholamines and alpha- and beta-adrenergic activities exerted minimum effect.

In addition to the type and intensity of exercise, other important determinants of athletic heart structure adjustments are the age, sex, race and the genetic component[24,25]. There is a consensus in literature that genetic factors should play an important role in ventricular hypertrophy development among athletes, in order to justify evident differences in cardiac changes and athletic performance, observed in individuals with the same anthropometric characteristics and submitted to the same

Table I - Minimum and maximum values, means and standard deviations of data obtained from simple exercise treadmill test

	HR		BP		T	VO_2 max	MET
	Initial	Final	Initial	Final	min	ml/kg/min	
Min.	36	163	110 x 60	170 x 70	10	46	14.6
Max.	67	197	140 x 90	220 x 90	21	77.3	22.4
Mean	55.7	179.9	127.7 x 80.5	191.5 x 80.2	12.6	63.64	19.1
SD	7.3	10.3	10 x 8.1	14.2 x 9.5	2.6	10.38	2.83

Table II - Minimum and maximum values, means and standard deviations of data obtained from cardiopulmonary tests

	HR		BP		T	VO_2	MET	LA_2 VO	%HR max	%LA HR
	Initial	Final	Initial	Final	min	ml/kg/min		ml/kg/min		max
Min	55	165	110 x 80	170 x 70	10:44	48.6	14	28.1	92.4	70.2
Max	67	197	140 x 90	210 x 85	12:18	52.1	15	38.6	107.7	89.8
Mean	61	178	128 x 81	190 x 77	11:35	51.3	14.6	32.4	99.2	79.4
SD	4.3	11.5	11.7 x 6.5	12.6 x 7.5	0.03	1.33	0.42	4.3	5.5	6.6

Table III - Main echocardiographic variables in athlete and control groups

Echocardiographic variables	Athletes (n=30)		Control (n=30)		p
	Mean (sd)	Variation	Mean (sd)	Variation	
Diameter of the aorta (mm)	33±3	26 a 38	32±4	24 a 38	NS
Left atrium diameter	39±4	25 a 42	34±4	24 a 40	<0.001
LV diastolic diameter	54±5	44 a 66	50±4	40 a 56	<0.001
LV systolic diameter	32±4	24 a 39	32±4	26 a 37	<0.001
Ventricular septum diastolic thickness	11.0±0.5	10 a 12	7.6±0.7	6 a 9	<0.001
Posterior wall diastolic thickness	11.0±0.6	10 a 12	7.6±0.7	6 a 9	<0.001
Left ventricular mass (g)	234±41	156 a 294	134±27	81 a 171	<0.001
Ejection fraction	0.70±0.05	0.61 a 0.79	0.60±0.05	0.53 a 0.73	<0001
% D (Shortening fraction)	40±4	33 a 49	36±4	31 a 47	<0.001

Table IV - Means of main echocardiographic variables obtained in athlete and control groups, indexed to body surface

Echocardiographic variables	Athletes (n=30)	Control (n=30)	p
Diameter of the aorta (mm/m2)	18±2	17±2	0.04
Left atrium diameter (mm/m2)	21±2	17±2	<0.001
LV diastolic diameter (mm/m2)	29±4	26±4	<0.001
LV systolic diameter (mm/m2)	17±3	17±3	NS
Ventricular septum diastolic thickness (mm/m2)	5.9±0.5	3.9±0.4	<0.001
Posterior wall diastolic thickness (mm/m2)	5.7±0.5	3.9±0.4	<0.001
Left ventricular mass (g/m2)	126±24	70±15	<0.001

Table V - Maximum and minimum values, mean and standard deviation of end diastolic volume (EdV), end systolic volume (EsV), ejection fraction (EF), ventricular wall diastolic and systolic thickness, in the athlete group

	EdV (ml)	EsV (ml)	EF (%)	Mass (g)	Diastolic thickness (mm)	Systolic thickness (mm)
Min.	70	20	57	130	11	15
Max.	140	53	72	240	19	26
Mean	99.07	36.8	63.67	162.93	13.67	18.87
SD	20.09	7.97	4.53	17.90	2.13	3.40

Table VI - Maximum and minimum values, mean and standard deviation of end diastolic volume (EdV), end systolic volume (EsV), ejection fraction (EF), ventricular wall diastolic and systolic thickness, in the control group

	EdV (ml)	EsV (ml)	EF (%)	Mass (g)	Diastolic thickness (mm)	Systolic thickness (mm)
Min.	85	18	56	90	7	9
Max.	135	42	75	135	11	11
Mean	130.00	30.00	60.00	110.00	8.00	10.00
SD	15.00	5.45	8.20	14.20	0.90	1.80

Table VII - Analysis of heart segmental contractility (assessed through tagging), of regional thickening and diastolic function of 15 athletes

	Regional thickening	Tagging	Diastolic function
Normal	15	13	11
Non-significant change	-	02	04

level of training[1,24,26]. For Pelliccia[27], hereditary factors influence cardiac dimensions, either through genetic control of hypertrophic response to athletic conditioning, or through genetic predisposition to support a more intensive physical training and reach higher performance levels during competition. Recently, Montgomery et al.[28] studied 400 army rookies before and after a 10-week period of strength and endurance training. At the end of the study, they observed an increase of the average left ventricular mass from 167 g to 197 g (an increase of 18%). Individuals were divided in three groups, according to angiotensin converting enzyme (ACE) genotype polymorphism: homozygotic insertion (I/I), heterozygotic insertion/deletion (I/D) and homozygotic deletion (D/D). The three groups, with deletion allele, had the greatest increase of left ventricular mass, which suggested that increased ACE levels play an important role in training-induced myocardial hypertrophy development.

In this study, echocardiographic assessment of left ventricular systolic function, represented by ejection fraction (0.61 to 0.79, mean of 0.70 ± 0.05) and by the fiber systolic shortening percentage (33 to 49%, mean of 40% ± 4), evidenced normal values in all cases, inclusively significantly higher than those from control group (0.53 to 0.73, mean of 0.60 ± 0.005, and 31 to 47%, mean of 36.0% ± 4, respectively). Thos e findings are in accordance to results from many cross-section studies, which compared groups of athletes from most different sports with sedentary control individuals[3,29-31].

Two studies deserve special attention. Among endurance and strength sports athletes, it was observed that several non-invasive contractility indexes used to assess left ventricular function were normal, despite the pronounced increase of ventricular cavity and thickness[30]. Another study[5] assessed the echocardiographic dimension of left ventricular cavity in 1,309 elite athletes, from 38 different sports modalities. According to a cut-off arbitrary level of 60 mm, they considered that left ventricular cavity was substantially increased in 185 athletes (14%). All of them had global systolic left ventricular function within normality limits and did not show segmental parietal motility abnormalities. After a 1-to-12-year follow-up (average of 4.7 years), the 185 athletes remained asymptomatic and did not show cardiac performance anomaly. The main determinants of left ventricular cavity dimension were the larger body surface and the participation in certain endurance sports (cycling, cross-country skiing and canoeing).

Results from assessment through magnetic resonance imaging (MRI) in this study equally show that, despite the increase of left ventricular mass and parietal thickness, athletes had normal ejection fraction (57 to 72%, average of 63.67% ± 4.53). Normal findings of regional movement, assessed by tagging, and measurement of regional thickening reinforce the conclusion that there was no impairment of heart contractile strength or left ventricular performance. Pluim et al.[32] assessed cardiac anatomy, function and metabolism through magnetic resonance imaging and spectroscopy among highly trained cyclists and control individuals. Left ventricular mass and end diastolic volumes, indexed by body surface, were significantly higher among cyclists. However, left ventricular ejection fraction, cardiac index and systolic parietal stress did not differ from those among control individuals. Phosphocreatine/adenosine triphosphate index was similar in both groups. For the authors, those findings indicate that physical exercise-induced left ventricular hypertrophy is only physiological adjustment.

Assessment of several echocardiographic of left ventricular diastolic function – velocity of E and A waves of mitral flowchart, E/A rate, E wave deceleration time, and isovolumetric relaxation time – in athletes from this study showed values uniformly within normality limits, under basal conditions.

By using angiography with radionuclides, Granger et al.[33] observed that athletes did not show changes in left ventricular filling, although left ventricular mass was 43% greater than the one in sedentary control group.

As opposed to athlete hypertrophy, diastolic ventricular dysfunction is identified in the vast majority of patients with systemic hypertension or hypertrophic myocardiopathy, regardless of hypertrophy level, presence of symptoms or outlet way blocking[32].

Myocardial texture nature, like echo intensity, can be examined in many ways. The simple codification through the color or pathological myocardial reflectivity shows an increase of fibrosis-associated echo amplitude. On the other hand, in athlete hypertrophy, echo amplitude or ultrasonic myocardial reflectivity are within normal limits, suggesting that physiological hypertrophy does not come along with fibrosis and other structural changes, observed under pathological conditions[33].

Response to exercise – It has been acknowledged for a long time that, under presence of left ventricular hypertrophy, exercise tests may show changes of ST-T typical of ischemic response due to disproportion between oxygen offer and consumption, even in absence of obstructive coronary atherosclerotic disease. In patients with left ventricular hypertrophy and normal coronary arteries at angiographic study, exercise treadmill test with typical ischemic response were reported in 38%[37] and 58%[38] of individuals.

In the present study, exercise treadmill test did not evidence, in any case, ischemic response to exercise, nor

symptoms, arrhythmias, abnormal behavior of heart rate or ventricular function were observed. Those results indicate that left ventricular hypertrophy does not induce to disproportion between oxygen offer and consumption, even under maximum exercise conditions. Such findings are in accordance to those reported among long distance runners[2], basketball players[3] and professional soccer players[29], many of which had documented left ventricular hypertrophy.

Maximum oxygen consumption (VO_2 max) is the main indicator of those adjustments and probably the most objective single indicator of physical training level. While a normal young adult, non-athlete, shows VO_2 max of approximately 35 ml/kg/min, among endurance athletes, that variable increases significantly (50%, in average)[22,24,30], sometimes exceeding 70ml/kg/min[20,21].

Physical capacity of the 30 athletes was determined through maximum oxygen consumption (VO_2 max), indirectly obtained, and its equivalent in MET. Fifteen athletes were randomly selected to be submitted to MRI, through direct measurement of O_2 consumption. Result classification was based on O_2 consumption table elaborated by Barros et al.[19], subdivided in four categories: unconditioned, conditioned, well-conditioned and elite athlete. Indexes achieved in this work were from well-conditioned athletes.

Many studies demonstrated that changes in left ventricular mass and ventricular cavity size with physical training and conditioning take place simultaneously with changes of VO_2 max[32,36,37,38], strongly suggesting that ventricular hypertrophy is associated with a better cardiac function[20].

Summarizing, results from this study evidenced that left ventricular hypertrophy of marathoners, with excellent level of training, has normal left ventricular function, both systolic and diastolic, high oxygen consumption and does not show anomalous responses at exercise treadmill test.

The reasons why left ventricular hypertrophy (LVH) of athletes has clearly different characteristics from hypertrophy associated to hypertension, hypertrophic cardiomyopathy and other pathological conditions, are not established, but some suggestions may be given, based on clinical and/or experimental findings.

The first and, probably, the most important is that pressure and volume overload resulting from intensive physical training only represents a hemodynamic stimulus for LVH development, without necessarily being followed by neurohumoral changes, as occurring in pathological hypertrophies. Experiments with animals[23] showed that exercise-associated hemodynamic overload is closely related with myocardial hypertrophy, whereas cardiac and plasma catecholamines and alpha- and beta-adrenergic activity only exert discreet effect.

More recent studies, using animal models with volume overload without activation of rennin-angiotensin system, induced myocytes hypertrophy, but not myocardial fibrosis. So, the main initial stimulus for myocardial hypertrophy is mechanical straining, whereas fibrosis-resulting stimuli are humoral[21,22,27]. Consequently, athlete's hypertrophy seems to be restricted to myocytes, without changing extracellular matrix and without causing interstitial fibrosis[1,20,21]. Some studies proved, through color codification or through ultrasonic myocardial reflectivity that pathologically hypertrophied myocardium shows and increase of fibrosis-associated echo amplitude, which does not happen in ventricular hypertrophy of athletes[34].

During physical training, sympathetic nervous system is activated. However, in rest periods, much longer every day, vagal preponderance[21,22] takes place that, probably, compensates for deleterial effects of catecholamines in myocardium, as well as activation of other neurohormonal systems by sympathetic nervous system.

The increase in the number of mitochondrias, capillary neoformation, normal activity of myosin ATPase observed in hypertrophied myocardium due to physical training, prevent from the disproportion between oxygen offer and consumption and the occurrence of ischemia, as opposed to what was observed in pathological hypertrophies[21,22].

Results from the present study, in a group of marathoners in a full sports activity period, allow for concluding that left ventricular hypertrophy observed in those athletes, assessed through non-invasive methods, represents an adaptative response to intensive and prolonged physical training, with purely physiological characteristics.

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