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Original article

CARDIOVASCULAR ADAPTIVE RESPONSE TO TRAINING IN ELITE ATHLETES. COMPARISON BETWEEN ENDURANCE AND NON-ENDURANCE ATHLETES

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Abstract

Introduction: The different structural modifications that have been described in the heart of the high-performance athlete depend on factors such as age, gender, type of sport, and the intensity and time dedicated to training.

Objectives: Evaluation of elite athletes through echocardiography for the description of cardiac structure and function, and the comparison between athletes with cardiorespiratory endurance and the rest of the athletes.

Methods: We performed the echocardiographic examination in 224 elite athletes, 96 women and 128 men aged 15 to 38 years (21.7 ± 5.3 years) and they were divided into 2 groups: "Endurance Group" (cardiorespiratory endurance) and "Non-Endurance Group" which included the rest of the sports. Univariate comparison between the two groups was performed by measuring 14 echocardiographic variables.

Results: In men, statistically significant higher values were identified in the endurance group for interventricular septum, left ventricular posterior wall, relative wall thickness (RWT), left ventricular mass index and left atrial dimension. In women, the endurance group had significantly lower heart rate values, and significantly higher left ventricular diastolic dimension with normal RWT.

Conclusions: Most of the echocardiographic variables showed higher sample means in the endurance athletes. In the subgroup of men from the Endurance Group, eccentric hypertrophy prevailed with a greater increase in wall thickness, as well as in the diameter of the left atrium, while in women the variables indicated eccentric hypertrophy at the expense of an increase in left ventricle diameter, without increased wall thickness.

Key words: elite athletes, endurance athletes, echocardiography, left ventricular hypertrophic, myocardial strain

Resumen

Respuesta adaptativa cardiovascular al entrenamiento en deportistas de élite. Comparación entre deportistas de resistencia y no resistencia

Introducción: Las diferentes modificaciones estructurales que han sido descritas en el corazón del deportista de alto rendimiento dependen de factores como la edad, el género, el tipo de deporte, la intensidad y el tiempo dedicados al entrenamiento.

Objetivos: Evaluación de atletas de élite por medio de la ecocardiografía para la descripción de la estructura y la función cardíacas, y la comparación entre deportistas de resistencia cardiorrespiratoria y el resto de los deportistas.

Métodos: Realizamos el examen ecocardiográfico en 224 deportistas de elite, 96 mujeres y 128 varones con edades de 15 a 38 años (21.7±5.3 años) y se dividieron en 2 grupos: "Grupo de Resistencia" (resistencia cardiorrespiratoria) y "Grupo de no Resistencia" el cual incluyó al resto de los deportes. Se realizó la comparación univariada de 14 variables ecocardiográficas entre los dos grupos.

Resultados: En los hombres se identificaron valores estadísticamente significativos más altos en el grupo de resistencia para septum interventricular, pared posterior, grosor parietal relativo, índice de masa del ventrículo izquierdo y aurícula izquierda. En las mujeres, el grupo de resistencia tuvo valores de frecuencia cardíaca más bajos con diámetro diastólico e índice de masa del ventrículo izquierdo significativamente mayores.

Conclusiones: La mayoría de las variables ecocardiográficas mostró valores mayores en los atletas de resistencia. En los hombres del Grupo de Resistencia, predominó la hipertrofia excéntrica con mayor incremento en el grosor parietal y del diámetro de la aurícula izquierda, mientras que en las mujeres las variables indicaron hipertrofia excéntrica a expensas de un aumento del diámetro del ventrículo izquierdo, sin incremento del grosor parietal.

Palabras clave: deportistas de élite, deportistas de resistencia, ecocardiografía, hipertrofia ventricular izquierda, deformación miocárdica.

KEY POINTS

Current knowledge

- Intensive sports practice generates clinical, electrocardiographic, morphological, and metabolic changes that result in the "athlete's heart."

Contribution of the article to current knowledge

- CeNARD is an ideal and advantageous institutional space for the echocardiographic evaluation of a large population of high-performance Argentine athletes. Significant differences were found in some echocardiographic variables according to gender and sport type. Women in the Endurance Group showed significantly higher values of septal thickness compatible with eccentric hypertrophy, while in men, they presented eccentric hypertrophy at the expense of a greater wall thickness.

Intensive sports practice leads to clinical, electrocardiographic, morphological, and metabolic changes that give rise to the athlete's heart. The first reference to what we now call "athlete's heart" dates to the late 19th century when Henschen et al.[1] described an increase in cardiac area by thoracic percussion in Swedish skiers. He considered two possible theories: it was either the consequence of an effective and healthy physiological adaptation or a possible borderline condition or disease. Subsequently, with the introduction of radiography and electrocardiography in cardiology practice, numerous studies showed that athletes presented suggestive changes of left ventricular hypertrophy.

For years, and to the present day, there has been uncertainty about whether these findings, a product of physiological adaptations to exercise, do or do not lead to a greater probability of developing events associated with heart disease in the long term[2]. This question has motivated many researchers to more deeply evaluate different aspects related to cardiac remodeling, systolic function, and diastolic function, among others. Cardiovascular physiology laboratories in Paris, Vienna, Berlin, and Italy in the 19th and 20th centuries, and more specifically the Schools of Mosso in Turin, Margaria and Cerretelli in Milan, and Cerquiglini and Luciani in Rome[3,4], stood out for the study of cardiovascular adaptations to exercise.

Echocardiography is a non-invasive tool widely used in sports cardiology to differentiate exercise-induced physiological adaptations from pathological causes such as hypertrophic cardiomyopathy, dilated cardiomyopathy, arrhythmogenic right ventricular dysplasia, etc. The first echocardiographic studies in this area were published on the Munich Olympics in 1972. Since then, it has been one of the most used methods, given its excellent cost-benefit ratio, to evaluate these aspects[5].

Morganroth et al.[6] was the first to highlight that there is a form of adaptation in non-endurance athletes (concentric LV hypertrophy) as opposed to dilation observed in endurance athletes (eccentric hypertrophy). In 56 athletes studied, they observed an increase in left ventricular end-diastolic volume and LV mass in athletes involved in isotonic exercise, while maintaining normal wall thickness. Athletes performing isometric exercise had a normal LV end-diastolic volume with an increase in wall thickness and LV mass[6].

There are various classifications of sports, with one of the most widespread dividing them according to the type of exercise: dynamic (isotonic) or static (isometric), and according to their intensity: low, moderate, or high[7].

Most sports are characterized by a combination of both types of exercise, but a group of them stand out for a marked predominance of aerobic metabolism, which we call endurance sports. Examples of the latter include Olympic disciplines such as long-distance running, marathon, rowing, cycling, triathlon, among others. These athletes must train to sustain a predominantly aerobic metabolism for an extended period, an objective impossible to achieve without the development of adaptive changes at the muscular and cardiorespiratory level. The rest of the disciplines comprise a very heterogeneous list of sports, but in these, the main objective to be achieved during training is not an increase in cardiorespiratory endurance, but the optimization of strength, speed, and muscular response, as is the case with soccer, tennis, weightlifting, or judo. These athletes achieve great performances but for shorter periods of time during which they acquire a significant oxygen debt that is fully or partially paid off throughout the practice.

Despite some lack of uniformity in the published literature regarding the way to group different sports, the most representative studies coincide with the results that show that changes in cardiac structure and function are observed more frequently and to a greater extent in cardiorespiratory endurance athletes than in non-endurance athletes [8-15].

Recently published by Pelliccia and Caselli[16] is the simplified classification of the most common Olympic sports, according to their relative isometric or isotonic components and their cardiovascular adaptations[17]. In our research, we decided to classify them into endurance athletes and non-endurance athletes, based on the objectives of the presented study.

High-performance sport in the Argentine Republic finds a space in the CeNARD where athletes who compete at the national and international levels can be evaluated in all aspects related to physical and psychological performance through medicine and physiology. This characteristic has allowed us to access a highly selected population of Argentine athletes to obtain data that had not been studied to date in relation to the objectives of this study.

The objective was the evaluation of elite athletes of both genders from Argentina using echocardiography to describe cardiac structure and function, and comparison between endurance athletes and non-endurance athletes.

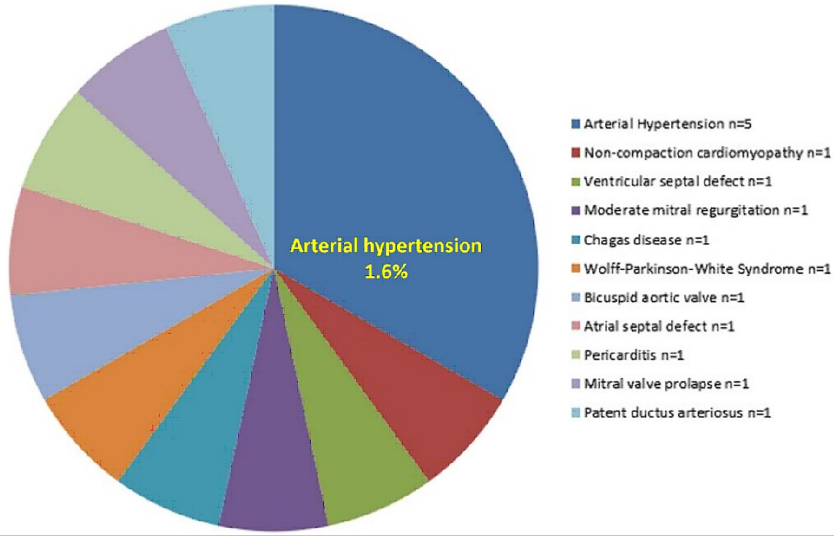
Methods

From July 2012 to November 2016, athletes of both genders with a physical training of more than 3 hours per day for at least 3 years, who represented the national and/or international level in competitions, and gave consent for a standardized echocardiographic evaluation were included. Of a total of 300 subjects, those with diagnosed organic and/or functional heart disease by clinical examination, ECG, or echocardiography were excluded. The following pathologies were found in 15 subjects (5%): arterial hypertension (n = 5), noncompaction cardiomyopathy (n = 1), ventricular septal defect (n = 1), moderate mitral regurgitation (n = 1), Chagas disease (n = 1), Wolff-Parkinson-White syndrome (n = 1), bicuspid aortic valve (n = 1), atrial septal defect (n = 1), pericarditis (n = 1), mitral valve prolapse (n = 1), and patent ductus arteriosus (n = 1) (Fig 1).

Paralympic athletes were not included, nor were subjects under 15 years old. The final sample consisted of 224 individuals, of whom 96 were women and 128 were men, with ages ranging from 15 to 38 years (21.7 ± 5.3 years). Initially, body mass index and body surface area were estimated using the Quetelet and Du Bois formulas, respectively.

Anthropometric characteristics by gender and age group are shown in Table 1. Heart rate and 14 echocardiographic variables were analyzed according to the recommendations of the American Society of Echocardiography: left ventricular diastolic diameter, left ventricular diastolic diameter index (LVDDI), interventricular septum thickness (IVS), left ventricular posterior wall thickness (LVPW), relative wall thickness (RWT), left ven-

Figure 1 | List of pathologies that were the reason for exclusion (n:15)



Arterial hypertension was detected in 1.6% (5/300) of the athletes

Table 1 | Anthropometric summary by gender and age group

	Women Age group (y.o)		
	15-19 (n = 43)	20-24 (n = 21)	≥25 (n 32)
Weight (kg)	60.9 ± 11.2	64.6 ± 10.7	63.8 ± 16.1
Height (m)	1.65 ± .,07	1.68 ± 0.09	1.66 ± 0.09
BMI (kg/m²)	22.3 ± 3.4	22.9 ± 3.5	23.0 ± 4.3
BSA (m²)	1.67 ± 0.16	1.73 ± 0.17	1.70 ± 0.21
	Men Age group (y.o)		
	15-19 (n = 61)	**20-24 (n = 46)**	**≥25 (n = 21)**
Weight (kg)	70.7 ± 10.4	75.9 ± 12.7	75.5 ± 10.2
Height (m)	1.76 ± 0.08	1.78 ± 0.08	1.78 ± 0.08
BMI (kg/m²)	22.7 ± 2.5	23.8 ± 3.0	23.8 ± 2.0
BSA (m²)	1.86 ± 0.16	1.94 ± 0.17	1.93 ± 0.16

BMI: body mass index; BSA: body surface area

tricular mass index (LVMI) using the Devereux M-mode formula, left atrial diameter (LA), aortic root diameter, inferior vena cava diameter (IVCD), E/A transmitral flow ratio, average E/e' ratio, right ventricular systolic tissue velocity (RVSV), and LV global peak longitudinal systolic strain by the "speckle tracking" method (LVLS). Normal values were defined for the following parameters: LVDDI <32 mm/m² (women) and <31 mm/m² (men); RWT < 0.42; LVMI <95 g/m² (women) and <115 g/m² (men); RVSTV ≥9.5 cm/s and LVLS ≥-17%. In addition, an IVS ≤11 mm and an LVPW ≤9 mm were considered normal. Evaluations were performed at rest. All echocardiographic measurements were performed by a cardiologist specializing in echocardiography and were carried out in the morning. For this purpose, a GE Vivid 7 echocardiograph with a 3.5 MHz transducer was used, and the data were obtained and recorded online.

The population was divided by gender into two groups: the so-called "Cardiorespiratory Endurance Group" (EG), which included all sports with a clear predominance of aerobic metabolism, and the Non-Endurance Group (NEG), which included the remaining sports.

The individuals came from 34 competitive sports. Their distribution according to the type of sport (cardiorespiratory endurance or non-endurance) is shown in table 2.

Statistical analysis

The data were analyzed descriptively by gender based on the established classification of sports. In addition, tests of hypothesis of equality of means between the two types of sports were performed using the independent samples t-test. Additionally, box plots were constructed to comparatively represent the distribution of echocardiographic variables data.

The level of statistical significance was set at 0.05. All analyses were performed using the R programming language and environment, version 3.5.2 (R Core Team, 2018).

The study was approved by the Ethics Committee of the Institution.

Informed consent was obtained from all included patients.

Results

Table 3 summarizes the main echocardiographic variables. A LVDDI ≥32 mm/m2 was measured in 21.8% of women (21/96), while an LVDDI ≥31 mm/m2 was present in 22.6% of men (29/128). The IVS was ≥12 mm only in men in 8.6% (11/128). A LVPW ≥ 10 mm was found in 3.1% of women (3/96) and in 28.1% of men (36/128). The LVMI was >95 g/m^2 in 30.9% (29/94) of women and >115g/m^2 in 34.1% (43/126) of men. The relative wall thickness was <0.42 in all but one woman. A ratio E/e' ≥ 8 was calcu-

Table 2 | Classification of sports

Classification of sports			
Endurance Group	**n**	**Non-endurance group**	**n**
Middle-distance Athletes	5	Sprint Athletics	4
Long-distance Athletes	1	Throwing athletics	9
Marathon	1	Car racing	1
Combined Athletics	1	Basketball	3
Canoeing	6	Beach Handball	2
Cycling	4	Boxing	14
Alpine skiing	5	Fencing	12
Swimming	24	Waterskiing	2
Speed Skating	5	Football (UK) – Soccer (USA)	1
Modern Pentathlon	10	Gimnastics	6
Rowing	12	Golf	2
Triathlon	7	Weightlifting	3
Total	81	Handball	4
		Field Hockey	6
		Judo	
		Karate	5
		Wrestling	15
		Netball	3
		Basque- Pelota	2
		Rugby	1
		Softball	5
		Squash	1
		Taekwondo	8
		Tennis	22
		Table Tennis	1
		Shooting	2
		Volleyball	3
		Total	143

lated in 7.7% of athletes (16/207), with a maximum value of 9 and absence of other indirect signs of diastolic dysfunction. Reliable views for measuring IVLS were only obtainable in 80% of the subjects. A lower (worse) value of -17% was found in 12.1% of men (13/107) but not in any woman. Of these, only one man also had other parameters of systolic dysfunction. The systolic function of the right ventricle was evaluated with tissue Doppler. 6.7% of athletes had values just below 9.5 cm/s, but all of them had tricuspid annular plane systolic excursion (TAPSE) values >17 mm.

In the analysis by type of sport, the sample was divided into EG = 81 athletes (31 females, 50 males) and NEG = 143 athletes (65 females, 78 males). In females, heart rate was significantly lower in EG than in NEG (60.1 ± 10.4 bpm and 64.5 ± 9.0 bpm, respectively, 95% CI -8.77 to -0.001, p<0.05). LVDDI was higher in EG compared to NEG (31.6 ± 2.3 mm/m^2 and 29.2 ± 2.7 mm/m^2, respectively, 95% CI 1.25 to 3.50, p<0.001). LVMI was higher in EG compared to NEG (95.9±15.9 g/m^2 and 82.4±13.0 g/m^2, 95% CI 7.39 to 19.67, p < 0.001).

In males, IVS was significantly higher in EG than in NEG (10.5±1.1 mm and 9.7 ± 1.2 mm, respectively, 95% CI 0.39 to 1.24, p < 0.001). LVPW was higher in ER compared to NEG (9.4 ± 1.0 mm and 8.8±1.1 mm, respectively, 95% CI 0.20 to 0.96, p < 0.01). Relative wall thickness also showed differences (EG 0.33 ± 0.04 and NEG 0.32 ± 0.04, 95% CI 0.002 to 0.03, p < 0.05). Like females, LVMI was higher in EG compared to NEG (117.2 ± 22.8 g/m^2 and 104.5 ± 19.1 g/m^2, respectively, 95% CI 5.17 to 20.15, p<0.01). Finally, the diameter of the left atrium was also higher in EG than in NEG (39.2 ± 3.7 mm and 37.5 ± 4.0 mm, 95% CI 0.27 to 3.06, p < 0.05, respectively). (Table 4)

Discussion

The first challenge when undertaking this research was to recruit a relevant number of athletes who represented the highest levels of competitive sports in our country. This was not an easy objective to achieve considering that the invitation to participate in a study of this nature, far from generating a special motivation for them, could provoke certain fear of the possibility of unexpected results that could condition the continuity of their practice.

On the other hand, an aspect that could be considered advantageous, such as the wide range of sports disciplines that we were able to gather, had as a counterpart a very heterogeneous composition in the non-Endurence Group. However, since the main objective of the work was to highlight the differential aspects of

Table 3 | Main echocardiographic variables

	Female n/total (%)	Male n/total (%)	Total n/total (%)
LVDDI ≥ 32mm/m^2	21/96 (21.8)		50/224 (22.3)
LVDDI ≥ 31mm/m^2		29/128 (22.6)	
FS < 25%	1/96 (1.04)	1/128 (0.7)	2/224 (0.8)
IVS ≥ 12mm	0/96 (0)	11/128 (8.6)	11/224 (4.9)
LVPW ≥ 10mm	3/96 (3.1)	36/128 (28.1)	39/224 (17.4)
RWT > 0.42	1/96 (1.0)	0/128 (0)	1/224 (0.4)
LVMI > 95g/m^2	29/94 (30.9)		72/220 (32.7)
LVMI > 115g/m^2		43/126 (34.1)	
E/e' ≥ 8	10/91 (10.9)	6/116 (5.1)	16/207 (7.7)
LVLS <-17%	0/73 (0)	13/107 (12.1)	13/180 (7.2)
RV tissue Doppler < 9.5 cm/s	4/90 (4.4)	10/116 (8.6)	14/206 (6.7)

Number and percentage of athletes whose measurements exceeded the values considered normal. LVDDI = left ventricular diastolic dimension index; FS = Fractional shortening; IVS = interventricular septum; LVPW = left ventricular posterior wall; RWT = relative wall thickness; LVMI = left ventricular mass index; E/e' = E/e' Relation; LVLS = left ventricular longitudinal strain; RV = right ventricular

Table 3 | VMean values analyzed by group in both genders

Women EG (n=31)	Women NEG (n=65)	Women Difference		Women IC95%		Men EG (n=50)	Men NEG (n=78)	Men Difference		Men IC95%
60.1 ± 10.4	64.5 ± 9.0	−4.39	p<0.05	−8.77 a −0.001	Heart Rate (beats/min)	56.8 ± 11.1	58.3 ± 9.1	−1.54	NS	−5.38 a 2.30
51.3 ± 2.9	49.8 ± 3.8	1.48	NS	−0.06 a 3.02	LVDD (mm)	56.3 ± 4.0	55.4 ± 4.1	0.82	NS	−0.63 a 2.28
31.6 ± 2.3	29.2 ± 2.7	2.38	p<0.001	1.25 a 3.50	LVDDI (mm/m²)	29.8 ± 2.0	29.2 ± 2.2	0.59	NS	−0.18 a 1.35
35.0 ± 4.4	33.7 ± 4.4	1.29	NS	-0.62 a 3.21	Shortening fraction (%)	32.6 ± 5.1	33.4 ± 4.4	-0.77	NS	-2.45 a 0.91
9.0 ± 1.1	8.8 ± 1.2	0.21	NS	−0.28 a 0.71	IVS (mm)	10.5 ± 1.1	9.7 ± 1.2	0.81	p<0.001	0.39 a 1.24
8.0 ± 1.0	7.8 ± 1.0	0.28	NS	−0.16 a 0.72	PW (mm)	9.4 ± 1.0	8.8 ± 1.1	0.58	p<0.01	0.20 a 0.96
0.31 ± 0.04	0.31 ± 0.05	0.001	NS	−0.02 a 0.02	Relative wall thickness	0.33 ± 0.04	0.32 ± 0.04	0.015	p<0.05	0.002 a 0.03
95.9 ± 15.9	82.4 ± 13.0	13.53	p<0.001	7.39 a 19.67	LVMI (g/m²)	117.2 ± 22.8	104.5 ± 19.1	12.66	p<0.01	5.17 a 20.15
35.5 ± 3.4	34.4 ± 3.9	1.05	NS	−0.56 a 2.66	Left atrium diameter (mm)	39.2 ± 3.7	37.5 ± 4.0	1.67	p<0.05	0.27 a 3.06
28.1 ± 3.3	27.1 ± 2.8	0.99	NS	−0.30 a 2.28	Aortic root diameter (mm)	31.3 ± 3.0	30.5 ± 3.6	0.73	NS	−0.48 a 1.95
16.9 ± 4.6	16.4 ± 4.1	0.58	NS	−1.29 a 2.45	Inferior vena cava (mm)	19.0 ± 4.1	18.4 ± 3.8	0.51	NS	−0.92 a 1.95
2.4 ± 0.7	2.3 ± 0.7	0.08	NS	−0.22 a 0.39	E/A	2.6 ± 0.8	2.4 ± 0.6	0.17	NS	−0.08 a 0.41
6.3 ± 1.1	6.4 ± 1.3	−0.11	NS	−0.65 a 0.43	E/e´	5.8 ± 1.1	5.9 ± 1.2	−0.07	NS	−0.50 a 0.37
12.0 ± 1.7	12.8 ± 2.0	−0.75	NS	−1.59 a 0.09	RVSV (cm/s)	12.5 ± 2.1	12.4 ± 1.9	0.14	NS	−0.60 a 0.88
−20.9 ± 2.1	−21.1 ± 2.0	0.18	NS	−0.82 a 1.17	LVLGS (%)	−19.4 ± 2.0	−19.4 ± 1.9	0.02	NS	−0.75 a 0.79

EG: endurance group. NEG: non endurance group. LVDD: left ventricular diastolic diameter. LVDDI: left ventricular diastolic diameter index. IVS: interventricular septum. PW: posterior wall. LVMI: left ventricular mass index. RVSV: right ventricular systolic velocity. LVLGS: left ventricular longitudinal global strain

the Endurance Group with respect to the rest of the athletes, this condition was not considered an obstacle.

In the same sense, we differentiated ourselves from most articles published on the subject by avoiding the isotonic vs. isometric, dynamic vs. static, or endurance vs. strength dichotomy. The literature referred to the athlete's heart clearly and almost unanimously shows that cardiorespiratory endurance athletes are those who present structural and functional changes with greater frequency and magnitude when compared with athletes from other areas. It is known that this physiological adaptation is based on the need to increase cardiac output to maximum values, to sustain the best possible aerobic condition for a prolonged period. We are not ignorant that there are many other sports with comparable levels of physical demand with this group, and that in some percentage, they also develop structural remodeling of the heart. But the predominance of constant cardiorespiratory aerobic activity allows us to differentiate endurance athletes from other athletes.

In our study, the EG encompasses subjects who, to achieve maximum efficiency during competition, require a type of physical training that needs to appeal to metabolic pathways and resources in a different way than what is required of other athletes. We believe that the idea of shifting the bias in that direction could better explain the presence, frequency, magnitude, and relevance of structural changes in the athlete's heart.

The chosen methodology was related to the availability of resources, both technical and human. The limited time available for each study and its corresponding recording forced us to limit the echocardiographic variables to be considered.

The anthropometric measurements, on which some values were indexed, allowed us to reliably compare both groups. And although it was not the objective of the study, it allowed us to better observe the differences between both genders. It also prompted us to exclude those under 15 years of age, since their stage in terms of anthropometric, metabolic, and hormonal development made the sample less homogeneous to consider.

The overall results are not surprising, as they coincide with what other authors have published in other parts of the world.

It is noteworthy that the septal wall thickness measured in our records exceeded normal values in less than 5%, exclusively in men, and that its maximum value did not exceed 13mm. The posterior wall, on the other hand, presented values above normality in 28.1% of men and 3.1% of women, with maximum values of 11 mm and 10 mm respectively.

Around 22% of the athletes showed some degree of dilation of the left ventricular cavity, and when applying the calculation of ventricular mass indexed by body surface area, almost 1/3 of the total showed left ventricular hypertrophy. However, there were no doubts about the physiological nature of it, taking into consideration the degree of increase in wall thickness (at the lower limit of the "gray zone"), the eccentric morphology of the hypertrophy, the normality of diastolic function expressed by means of tissue Doppler, as well as the LV longitudinal strain (LVLS) within normal values.

Of the 224 subjects evaluated, only 1, a 24-year-old male trained for triathlon, presented eccentric hypertrophy (LVDDI 33mm/m^2; RWT 0.33; LVMI 134g/m^2) with lower-than-normal left ventricular systolic function indices (Shortening fraction 23%; LVLS -13.3%). Left ventricular diastolic function was normal, evaluated by transmitral Doppler, tissue Doppler, and E/e' ratio, and right ventricular function was preserved. This athlete continues his training currently, but with more rigorous controls. The rest of the athletes exhibited normal parameters of diastolic and systolic function.

When analyzing the sample by sports group, significant differences were found between them. While the increase in LVMI in the EG was evident in both genders, the male population stood out for presenting a greater increase in wall thickness relative to cavity growth, while maintaining eccentric morphology. In contrast, in women in the same group, the increase in LVMI was due to greater ventricular dilation without changes in wall thickness.

This disparity in morphological changes between sexes is comparable to what has been published[18,19], but there are only hypotheses that can explain this divergence. Among other things, it is possible that differences in lean body mass between men and women may be a factor to consider when choosing how to index measurements, as proposed by Giraldeau et al[20], who found an 8-percentage point difference in body fat in favor of women, which reduced sex differences in the measurement of LV mass and ventricular and atrial dimensions when these measurements were indexed by lean body mass.

The stimulating effect of testosterone on the development of ventricular hypertrophy and peripheral resistance contrasts with that of estrogens, which have an inhibitory effect on hypertrophy and a reduction in peripheral resistance mediated by nitric oxide[21-25].

Left ventricular diastolic function was evaluated using the E/A ratio and E/e' ratio, and as demonstrated by other authors[26], no diastolic dysfunction of the left ventricle was detected in any of the athletes, nor were there statistically significant differences between the groups. Some published studies have reported an increase in the diameter of the aortic root compared to the non-athlete population, but within normal ranges. It has also been reported that the diameter of the aortic root is larger in strength athletes than in endurance athletes[27-29]. In our study, we only compared these values between the two groups and found no abnormal values or significant differences.

The diameter of the inferior vena cava at expiration was measured in 96% of the athletes, and we found no differences between the GR and the GO. However, as a finding, we detected diameters greater than 20 mm in 10.7% of women and 30% of men. Other studies dedicated to this point have obtained similar results[30-32].

The right ventricular systolic function was normal in all athletes, mainly defined by tissue Doppler, with no statistically significant differences between the two analyzed groups. Other authors have reported slightly higher values, with mean values between 11.8 and 15.3 cm/s, compared to 12-12.8 cm/s in our population[33,34].

The analysis of LV longitudinal strain (LVLS) by speckle tracking to observe the behavior of ventricular and atrial contraction and relaxation mechanics has become widely used in clinical cardiology[35]. There is a growing number of research studies on left ventricular strain in athletes, which have studied it from different cutting planes (longitudinal, radial, circumferential), as well as strain rate, rotation, and torsion. In these studies, the characteristics of selected populations based on the type of sport, athlete profile (professional or amateur), gender, age, and circumstances under which the exams were conducted (rest, post-exertion, previous training time) differ so much from each other that we cannot yet speak of certainties in this field[36]. In this sense, our data have reflected what some authors have previously published in populations with similar characteristics. Caselli et al.[37] demonstrated that, despite presenting values within the range of normality, LVLS in athletes is lower compared to controls. Similarly, all athletes in our study presented normal values of LVLS, although in many cases near the generally accepted lower limit.

We must recognize that when we talk about cardiac remodeling or adaptive changes, it implies having documented changes over a specific period. Our study is methodologically designed as a cross-sectional analysis of a population, without longitudinal follow-up. In this sense, it is worth mentioning a study published by Weiner et al.[38], which explains exercise-induced cardiac remodeling as changes in cardiac structure and function that occur in response to physical training. In young athletes, it would have a pattern of phases. A first acute phase of adaptation characterized by LV dilation, improved LV relaxation, and increased LV torsion, while the chronic training phase is distinguished by thickening of the LV walls, an increase in compliance at the end of diastole, and a reduction of apical rotation and peak systolic torsion at rest. These authors conclude that the duration of training represents an important determinant of the magnitude and geometry of exercise-induced cardiac remodeling, which in turn depends on a series of factors such as age, gender, race, and sport discipline[38].

Limitations of the study: The size of the final sample considered, as well as the heterogeneous composition of the NEG, was limited for operational reasons. Nevertheless, the EG was composed of a representative number of athletes with similar characteristics that allowed us to differentiate it reliably from the NEG.

Although the lack of a control group could be questioned, we believe that the objectives of this work do not require it, since the measurements obtained in the overall analysis are compared with normal values defined by consensus, and in the analysis by groups, these measurements and calculations are relative to each other.

In conclusion, the results obtained in this study provide useful information and reinforce the concepts presented in other studies. It is important to highlight that the population included in this study has anthropometric characteristics specific to our region.

We hope that the resulting echocardiographic database from this study becomes a benchmark for evaluations of athletes who come annually to CeNARD and other sports medicine centers to improve their performance. Additionally, we are confident that this database can be used as a starting point for new research in the field.

Conflict of interest: None declare

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