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How Does Cardiac Remodeling Occur in Children Playing Different Types of Amateur Sports? A Single-Center Study from Türkiye

Farklı Amatör Spor Dallarında Oynayan Çocuklarda Kardiyak Remodeling Nasıl Gerçekleşiyor? Türkiye'den Tek Merkezli Bir Çalışma

ORIGINAL ARTICLE
KLİNİK ÇALIŞMA

ABSTRACT

Objective: Regular intense exercise may result in cardiac remodeling, which can be identified through echocardiographic examinations. This study aims to highlight how cardiac changes vary based on the type and duration of sports participation.

Method: The study included children aged 8-18 years (n = 241), who were divided into three groups: beginners, dynamic dominant athletes, and static dominant athletes. Cardiac remodeling was categorized into concentric hypertrophy, eccentric hypertrophy, and concentric remodeling based on increased values of left ventricular mass and relative wall thickness.

Results: Mean left ventricular end-diastolic diameters, z-scores, and left atrial diameters were significantly lower in the static group compared to the dynamic group. Among participants, excluding beginners, most common echocardiographic change was an increased z-score in the interventricular septal dimension during diastole (25.3%), followed by an increase in the left atrial diameter in diastole, left ventricular posterior wall thickness in diastole, left ventricular end-diastolic diameter, and left ventricular end-systolic diameter. In both dynamic and static groups, excluding beginners, the most prevalent hypertrophic pattern was eccentric hypertrophy. Overall, 35% of dynamic dominant athletes and 62% of static dominant athletes exhibited some form of remodeling. Additionally, interventricular septum size and left ventricular end-diastolic diameter were associated with the training period.

Conclusion: Our findings indicate that enlargement of the left ventricle and left atrium diameters is more pronounced in dynamic athletes, whereas changes in left ventricular mass are more prominent in static athletes. We believe that monitoring amateur child athletes with an understanding of these changes is important.

Keywords: Amateur sport, cardiac remodeling, children, echocardiography

ÖZET

Amaç: Düzenli yoğun egzersiz, ekokardiyografik incelemelerde tanınabilen bazı kardiyak yeniden şekillenmelere neden olabilir. Bu çalışmada amaç, kalpteki değişikliklerin spor türüne ve süresine bağlı olarak nasıl farklılık gösterdiğine dikkat çekmektir.

Yöntem: 8-18 yaş arası çocuklardan oluşan katılımcılar (n=241) 3 gruba ayrıldı: spora yeni başlayanlar, dinamik baskın sporcular ve statik baskın sporcular. Kardiyak yeniden şekillenme tipleri, sol ventrikül kütlesi ve relatif duvar kalınlığının artan değerlerine göre konsantrik hipertrofi, eksantrik hipertrofi ve konsantrik yeniden şekillenme olarak sınıflandırıldı.

Bulgular: Sol ventrikül diyastolik sonu çaplarının z-skorları ve sol atriyum çaplarının ortalamaları statik grupta dinamik gruba göre anlamlı derecede düşüktü. Yeni başlayanlar hariç, en sık görülen ekokardiyografik değişiklikler sırayla, diyastolik interventriküler septum boyutu (%25,3), sol atriyum diyastolik çap, sol ventrikül arka duvar diyastolik kalınlık, sol ventrikül diyastol sonu çapı ve sol ventrikül sistol sonu çapı z skorlarında artış idi. Yeni başlayanlar hariç, en sık hipertrofi çeşidi, hem dinamik hem de statik gruplarda eksantrik hipertrofiydi. Dinamik baskın sporcuların %35'i ve statik baskın sporcuların %62'si bir tür remodeling gösterdi. Interventriküler septum boyutu ve sol ventrikül diyastol sonu çapı antrenman süresi ilişkilidir.

Sonuç: Sonuçlarımıza göre, dinamik atletlerde sol ventrikül ve sol atriyum çaplarının genişlemesi belirginken, statik atletlerde ise sol ventrikül kütle değişiklikleri ön plandadır. Bizim görüşümüze göre, amatör çocuk atletleri bu değişiklikleri anlayarak izlemek önemlidir.

Anahtar Kelimeler: Amatör spor, kardiyak remodelling, çocuklar, ekokardiyografi

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Transthoracic echocardiography is recommended for preparticipation screening when an athlete presents with symptoms, abnormal findings on electrocardiography (ECG), or a family history of sudden death or cardiomyopathy before the age of 40.[1]

Adaptive electrical, structural, and functional cardiac changes following regular intense exercise are referred to as exercise-induced remodeling.[2] Cardiac adaptations that occur during exercise are more pronounced in structural left ventricular parameters, and these changes are influenced by exercise intensity.[3,4]

Exercise is primarily classified into dynamic and static categories. Dynamic exercise involves changes in muscle length and joint motion through rhythmic contractions, resulting in relatively small intramuscular force. In contrast, static exercise involves little or no change in muscle length or joint motion, leading to relatively large intramuscular power. Most physical activities incorporate both static and dynamic components, and sports are classified accordingly by Mitchell.[5] Cardiac adaptation mechanism varies based on the type of sport. During dynamic exercise, there is a significant increase in heart rate, cardiac output, stroke volume, and systolic blood pressure; a modest increase in mean arterial pressure; and a decrease in diastolic blood pressure and total peripheral resistance. On the other hand, static sports lead to a slight increase in heart rate and cardiac output, no change in stroke volume, a noticeable increase in systolic, diastolic, and mean arterial pressure, and no considerable change in total peripheral resistance. Thus, the impact on the cardiovascular system varies based on exercise type, with dynamic exercise imposing a volume load and static exercise imposing a pressure load.[5] Cardiac hypertrophy can be classified as either eccentric or concentric. In eccentric hypertrophy, end-diastolic volume increases, whereas in concentric hypertrophy, it does not change. Some relevant studies have identified eccentric hypertrophy as the most common form of cardiac remodeling.[6,7]

Cardiac remodeling due to regular exercise becomes noticeable after six months. However, while only changes in left ventricular mass are expected within the first six months, left ventricular end-diastolic diameter increases over a period from six months to three years, depending on the type of sport.[8]

Amateur athletes, unlike their professional counterparts, have the flexibility to decide whether to participate in competitions. Additionally, the social dynamics surrounding these two groups differ significantly. While hedonism and health are key motivations for amateur athletes, the performance-driven effort/reward duality is more dominant among professional athletes.[9] Furthermore, professional athletes undergo more regular health evaluations through their sports clubs, whereas amateur athletes do not receive the same level of medical oversight. For this reason, we aimed to investigate the cardiac assessments of amateur athletes.

This study aims to address the following questions in amateur child athletes:

1. What is the incidence of left ventricular hypertrophy, left ventricular dilatation, and left atrial dilatation?
2. What is the incidence of eccentric and concentric hypertrophy based on the type of sport?
3. How do cardiac changes vary according to age, training intensity, and duration of training?

ABBREVIATIONS

BMI	Body mass index
ECG	Electrocardiography
EF	Ejection fraction
IVSD	Interventricular septal dimension in diastole
LAD	Left atrial diameter in diastole
LGE	Late gadolinium enhancement
LV	Left ventricular
LVEDD	Left ventricular end-diastolic diameter
LVESD	Left ventricular end-systolic diameter
LVM	Left ventricular mass
LVMI	Left ventricular mass index
LVPWT	Left ventricular posterior wall thickness in diastole
MRI	Magnetic resonance imaging
RWT	Relative wall thickness

Materials and Methods

Study Population

Among all patients who visited the pediatric cardiology outpatient clinic for preparticipation sports examination, 241 were included in this prospective study, of whom 100 (41.5%) were girls. Each participant underwent a single echocardiographic evaluation during their examination. The participants were categorized into three groups:

1. Beginner Group: Children who applied for medical clearance to engage in sports without prior experience.
2. Dynamic Dominant Athletes Group (hereafter referred to as the Dynamic Group): Children who applied for medical clearance before obtaining a sports license while regularly participating in dynamic dominant sports.
3. Static Dominant Athletes Group (hereafter referred to as the Static Group): Children who applied for medical clearance before obtaining a sports license while regularly participating in static dominant sports.

Athletes were classified based on Mitchell's sport classification[5] according to the most dominant aspect of their sport. For instance, since sports such as wrestling and boxing are categorized as medium-heavy static sports, athletes participating in these sports were placed in the static dominant group. Conversely, sports such as swimming and running, which fall under the medium-heavy dynamic category, were classified within the dynamic dominant group.

Figure 1 illustrates the sports in which the participants of this study engage, along with their respective percentages. Athletes in the dynamic dominant and static dominant groups were further categorized based on the duration of their training for additional analysis. The training duration categories were defined as 3-12 months, 12-36 months, and more than 36 months. Training intensity was determined by the number of hours participants trained per week.

The inclusion criteria were as follows: children aged 8-18 years; no history of early sudden death (below age 40) or arrhythmia in

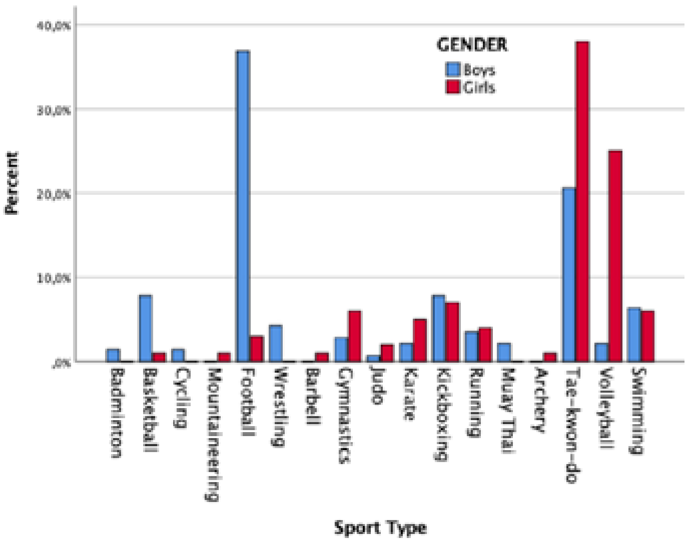

Figure 1. Sports engaged in by participants along with their respective percentages.

the family; absence of symptoms such as syncope or chest pain during exercise; a normal cardiac physical examination; normal blood pressure; and normal findings on both electrocardiography and echocardiography. Except for the beginner group, children in the dynamic dominant and static dominant groups were required to have engaged in regular training for at least four hours per week for a minimum of two months. Children diagnosed with serious acquired or congenital heart diseases affecting cardiac hemodynamics, as well as those with poor-quality echocardiographic images, were excluded from the study.

The body mass index was calculated using the Haycock formula: Body Mass Index (BMI) = Body Weight (kg) / Body Height^2 (m^2).[10] A mercury sphygmomanometer was used to measure blood pressure.

Echocardiographic Evaluation

A Philips IE33 color ultrasound system equipped with S8-3 and S5-1 sector array transducers was used to perform comprehensive Doppler echocardiography. Probe frequency ranged from 3-8 MHz and 1-5 MHz, with probe selection based on patient size and age. As commonly practiced, higher-frequency probes were used for younger children. Mean values were obtained from three to five consecutive cardiac cycles. Using M-mode view, left ventricular mass and relative wall thickness were calculated according to the formulas established by the American Society of Echocardiography.[11]

Left Ventricular Mass (LVM) = 0.8 (1.04 ([Left Ventricular End-Diastolic Diameter + Left Ventricular Posterior Wall Thickness in Diastole + Interventricular Septal Dimension in Diastole] 3 – [Left Ventricular End-Diastolic Diameter] 3)) + 0.6 g. Left ventricular mass index was then computed by dividing the left ventricular mass by the body surface area. Normal range for the left ventricular mass index (LVMI) was determined as 40-104 for females and 40-120 for males.[12]

Relative Wall Thickness = (Interventricular Septal Dimension in Diastole + Left Ventricular Posterior Wall Thickness in Diastole) / Left Ventricular End-Diastolic Diameter. Normal range was 0.19-0.47 for females and 0.21-0.42 for males.[12]

Accordingly, when both left ventricular mass and relative wall thickness increase, the resulting phenomenon is concentric hypertrophy. When left ventricular mass increases while relative wall thickness remains within the normal range, the condition is classified as eccentric hypertrophy. Conversely, when left ventricular mass remains normal but relative wall thickness increases, the condition is referred to as concentric remodeling.[13]

To calculate the left ventricular ejection fraction, modified Simpson's rule was applied using two-dimensional echocardiographic images with the following formula: Ejection Fraction (EF) = (Left Ventricular (LV) End-Diastolic Volume) - (LV End-Systolic Volume) / LV End-Diastolic Volume.[11] Normal range for the left ventricular ejection fraction was established as 58-76%.[12]

Since evaluations in the pediatric age group are commonly based on z-scores, the z-scores of all M-mode parameters, including the left ventricular end-diastolic diameter (LVEDD), left ventricular end-systolic diameter (LVESD), interventricular septal dimension in diastole (IVSD), left ventricular posterior wall thickness in diastole (LVPWT), and left atrial diameter in diastole (LAD), were calculated using the Parameter (z) calculator program.[14]

For the analysis of left ventricular diastolic function, mitral E-wave (rapid diastolic filling) and A-wave (atrial contraction) were obtained through the four-chamber view using pulsed Doppler echocardiography. E/A ratio was then calculated for each participant.

Statistical Analysis

All data were analyzed using SPSS (the Statistical Package for the Social Sciences) for Windows 19.0 (IBM Corp., Armonk, NY, USA). After conducting descriptive statistics and normality tests, either the independent-sample t-test or Mann-Whitney U test was used to compare numerical data. For categorical data analysis, Chi-square test and Fisher's Exact tests were applied. To assess the relationship between numeric variables, linear regression test was used. A p-value of < 0.05 was considered statistically significant.

Written informed consent was obtained from the legal guardians of all the participants. The study was approved by Ankara Atatürk Sanatorium Training and Research Hospital Clinical Research Ethics Committee (Approval Number: 2012-KAEK-15/2524, Date: 24.05.2022), and conducted in accordance with the Declaration of Helsinki.

Results

A detailed summary of the study group characteristics, including age, height, weight, body surface area, body mass index, length of training, training intensity, blood pressure, and basic electrocardiographic findings, is presented in Table 1. The dynamic group had a significantly higher mean height and body surface area than the beginner group. Additionally, mean resting heart rate was significantly lower in the dynamic group compared to both the beginner group and the static group. Median length of training was 12 months (range: 4-120 months) in the dynamic group and 10 months (range: 4-108 months) in the static group.

Table 1. Detailed Characteristics of the Study Groups

	Beginner (n = 90) Mean ± SD	Dynamic Group (n = 89) Mean ± SD	Static Group (n = 62) Mean ± SD	P[1]	P[2]	P[3]
Age, years	12.2 ± 2.5	13.1 ± 2.4	12.2 ± 2.8	0.051	0.998	0.175
Height, cm	153.3 ± 13.6	160.1 ± 12.9	155.2 ± 12.9	**0.003***	0.759	0.077
Weight, kg	47.1 ± 14.4	51.1 ± 12.3	47.1 ± 12.1	0.133	0.997	0.146
BSA, m^2	1.41 ± 0.26	1.50 ± 0.23	1.43 ± 0.23	**0.027***	0.943	0.133
BMI, kg/m^2	19.6 ± 3.85	19.7 ± 3.18	19.2 ± 3.24	0.998	0.929	0.833
Length of training, months, median (range)	–	12 (4–120)	10 (4–108)	**0.0001***	**0.0001***	0.080
Training intensity, hours/week	–	5.4 ± 4.3	5.1 ± 2.9	**0.001***	**0.001***	0.911
SBP, mmHg	113.3 ± 9.2	115.2 ± 8.6	113.3 ± 8.1	0.402	0.996	0.405
DBP, mmHg	63.7 ± 8.9	62.1 ± 8.8	64.2 ± 8.5	0.573	0.977	0.385
ECG						
HR at rest (beats/min)	86.5 ± 15.4	75.7 ± 14.4	82.6 ± 14.2	**0.000***	0.293	**0.013***
PR duration	127.4 ± 16.8	130.6 ± 16.3	128.1 ± 15.3	0.495	0.990	0.725
QTc duration	385.6 ± 45.1	388.1 ± 47.7	382.7 ± 52.5	0.980	0.977	0.889

[1]Significant differences between beginner and dynamic groups; [2]Significant differences between beginner and static groups; [3]Significant differences between dynamic and static sports groups; *Significant difference ($P < 0.05$). BMI, Body Mass Index; BSA, Body Surface Area; DBP, Diastolic Blood Pressure; ECG, Electrocardiography; HR, Heart Rate; SBP, Systolic Blood Pressure.

Table 2. Echocardiographic Findings of the Study Groups

	Beginner (n = 90) Mean ± SD	Dynamic Group (n = 89) Mean ± SD	Static Group (n = 62) Mean ± SD	P[1]	P[2]	P[3]
IVSD (mm)	7.92 ± 1.40	8.19 ± 1.59	8.10 ± 1.63	0.597	0.841	0.986
IVSD-z	1.04 ± 1.25	1.09 ± 1.36	1.21 ± 1.49	0.991	0.838	0.940
LVPWT (mm)	7.66 ± 1.52	8.01 ± 1.34	7.94 ± 1.48	**0.033***	0.623	0.604
LVPWT-z	0.49 ± 0.99	0.52 ± 0.91	0.63 ± 0.88	0.994	0.741	0.854
LVEDD (mm)	40.8 ± 3.49	42.8 ± 3.91	41.09 ± 3.25	**0.005***	0.967	**0.008***
LVEDD-z	−0.64 ± 0.67	−0.28 ± 0.90	−0.60 ± 0.74	**0.008***	0.976	**0.053***
LVESD (mm)	25.8 ± 2.60	27.1 ± 2.38	26.49 ± 1.95	**0.003***	0.253	0.244
LVESD-z	−0.49 ± 0.57	−0.33 ± 1.31	−0.31 ± 0.51	0.612	0.113	0.999
LAD (mm)	27.7 ± 3.06	29.03 ± 3.34	27.64 ± 3.06	**0.019***	0.999	**0.027***
LAD-z	0.01 ± 0.82	0.18 ± 0.88	0.01 ± 0.84	0.440	1.000	0.551
LVM (gr)	91.98 ± 34.29	135.51 ± 38.27	163.70 ± 52.13	**0.0001***	**0.0001***	**0.0001***
LVMI (g/m^2)	63.97 ± 14.02	89.91 ± 22.68	111.69 ± 24.99	**0.0001***	**0.0001***	**0.0001***
RWT (mm)	0.378 ± 0.06	0.384 ± 0.07	0.391 ± 0.06	0.875	0.487	0.906
Mitral E wave (cm/s)	1.00 ± 0.14	1.03 ± 0.12	1.29 ± 0.18	0.247	1.000	0.453
Mitral A wave (cm/s)	0.61 ± 0.10	0.59 ± 0.11	0.58 ± 0.10	0.462	0.278	0.972
E/A ratio	1.66 ± 0.30	1.80 ± 0.36	1.75 ± 0.39	0.018	0.354	0.808
TAPSE	22.0 ± 2.71	22.4 ± 2.46	22.4 ± 4.82	0.623	0.924	1.000
EF (%)	71.2 ± 5.12	71.5 ± 5.61	71.37 ± 5.35	0.978	0.994	1.000
Thoracic aorta (mm)	14.0 ± 5.02	14.1 ± 2.19	13.86 ± 1.91	1.000	0.983	0.880

[1]Significant differences between beginner and dynamic groups; [2]Significant differences between beginner and static sports groups; [3]Significant differences between dynamic and static sports groups; *Significant difference ($P < 0.05$). A wave, A-Peak Late-Diastolic Velocity; E wave, E-Peak Early-Diastolic Velocity; EF, Ejection Fraction; IVSD, Interventricular Septum in Diastole; LAD, Left Atrium Diameter; LVEDD, Left Ventricular End-Diastolic Diameter; LVESD, Left Ventricular End-Systolic Diameter; LVM, Left Ventricular Mass; LVMI, Left Ventricular Mass Index; LVPWT, Left Ventricular Posterior Wall Thickness; RWT, Relative Wall Thickness; TAPSE, Tricuspid Annular Plane Systolic Excursion.

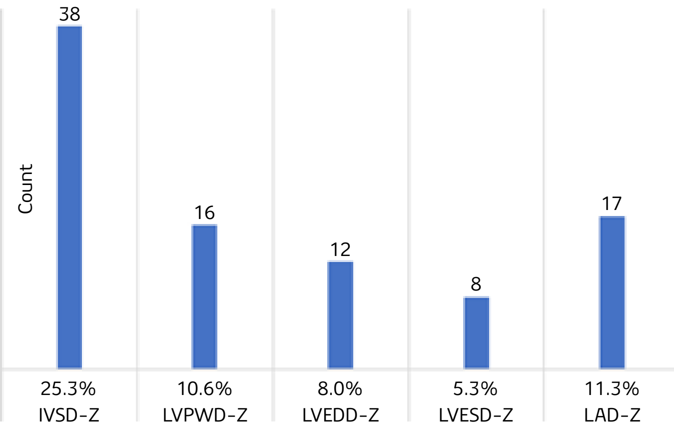

Figure 2. The number and percentage of athletes whose M-mode measurements exceed a z-score of 2.

Mean training intensity was 5.4 ± 4.3 hours in the dynamic group and 5.1 ± 2.0 hours in the static group.

Echocardiographic findings by groups are presented in Table 2. A significant difference was observed in mean LVPWT, LVEDD, z-score of LVEDD, LVESD, and LAD between the beginner group and the dynamic group. Mean values of these parameters were significantly lower in the static group than in the dynamic group. Additionally, LVM and LVMI progressively and significantly increased in the following order: beginner group < dynamic group < static group.

Excluding the beginner group, M-mode measurements of athletes with a z-score greater than 2 are shown in Figure 2. Most common echocardiographic change was an elevated z-score of IVSD (25.3%), followed by an increased z-score of LAD, z-score of LVPWT, z-score of LVEDD, and z-score of LVESD, in decreasing order.

Participants were analyzed based on remodeling patterns. Most common hypertrophic pattern was eccentric hypertrophy in both the dynamic group (12 athletes, 13.5%) and the static group (23 athletes, 37.1%). Additionally, concentric remodeling was identified as the most prevalent remodeling pattern in the dynamic group. In contrast, the incidence of concentric remodeling was nearly the same in the beginner group and the static group, occurring in approximately 5–7% of participants. Overall, 35% of dynamic dominant athletes and 62% of static dominant athletes exhibited some form of remodeling, including concentric remodeling. Table 3 presents the distribution of cardiac remodeling types with corresponding percentages within each group.

Table 3. Distribution of Cardiac Remodeling Types by Groups with Left Ventricular Mass Index (LVMI) and Relative Wall Thickness (RWT) > 95th Percentile

	Beginner (n = 90)		Dynamic Group (n = 89)		Static Group (n = 62)	
	n	%	n	%	n	%
Concentric hypertrophy	0	0	6	18.1	14	35.0
Eccentric hypertrophy	0	0	12	36.4	23	57.5
Concentric remodeling	7	100	15	45.5	3	7.5
Total	7	100	31	100	37	100

LVMI, Left Ventricular Mass Index; RWT, Relative Wall Thickness.

We found that eccentric hypertrophy developed as early as four months after the onset of regular exercise, whereas concentric hypertrophy occurred only after at least six months of training. When athletes were grouped based on the length of training, the z-score of IVSD was significantly higher in participants who had been training for more than 36 months compared to those training for 3-12 months (P = 0.07) and 12-36 months (P = 0.02). Similarly, left ventricular mass index values were significantly higher in participants with more than 36 months of training compared to those training for 3-12 months (P = 0.001) and 12-36 months (P = 0.04). However, no differences were found between 3-12 month and 12-36 month groups regarding the z-score of IVSD and left ventricular mass index parameters. Additionally, there were no statistical differences in other parameters, including the z-score of LVEDD, z-score of LVESD, z-score of LAD, and z-score of LVPWT among the three groups.

We also conducted a linear regression analysis to evaluate the relationship between M-mode measurements and age, length of training, and training intensity. This analysis revealed a significant positive correlation between length of training and both the z-score of IVSD and z-score of LVEDD. However, the remaining parameters showed no correlation with age, length of training, or training intensity (Table 4).

Excluding beginners, dynamic dominant and static dominant athletes were compared based on gender. Participants were comparable in terms of age, weight, BMI, and training intensity. However, height and body surface area were significantly higher in boys than in girls (P = 0.002 and P = 0.027, respectively). Additionally, parameters such as IVSD, IVSD-z, LVPWT, LVEDD, LVEDD-z, LAD, LVM, and LVMI were significantly higher in boys than in girls (Table 5).

Table 4. Results of Multivariate Linear Regression Analysis

	IVSD-z		LVPWT-z		LVEDD-z		LVESD-z		LAD-z	
	ß	P	ß	P	ß	P	ß	P	ß	P
Age, years	0.036	0.587	-1.186	0.237	0.093	0.158	0.118	0.075	0.017	0.440
Length of training, months	0.212	0.002*	0.128	0.061	0.158	0.020*	0.124	0.066	1.779	0.076
Training intensity, hours	-0.012	0.865	-0.079	0.522	-0.108	0.118	-0.734	0.464	0.179	0.858

ß, Standardized Regression Coefficient; IVSD, Interventricular Septum in Diastole; LAD, Left Atrium Diameter; LVEDD, Left Ventricular End-Diastolic Diameter; LVESD, Left Ventricular End-Systolic Diameter; LVPWT, Left Ventricular Posterior Wall Thickness.

Table 5. Comparison of Echocardiographic Parameters of Athletes by Gender

	Boys (n = 93)	Girls (n = 58)	P
IVSD (mm)	8.43 ± 1.58	7.66 ± 1.48	**0.003***
IVSD-z	1.33 ± 1.49	0.82 ± 1.24	**0.027***
LVPWT (mm)	8.18 ± 1.39	7.73 ± 1.33	**0.050***
LVPWT-z	0.63 ± 0.89	0.52 ± 0.93	0.460
LVEDD (mm)	42.9 ± 4.01	40.98 ± 2.74	**0.001***
LVEDD-z	–0.30 ± 0.91	–0.60 ± 0.75	**0.031***
LVESD (mm)	27.1 ± 2.31	26.4 ± 1.90	0.069
LVESD-z	–0.23 ± 0.63	–0.47 ± 1.49	0.242
LAD (mm)	29.06 ± 3.40	27.62 ± 2.72	**0.005***
LAD-z	0.17 ± 0.89	0.02 ± 0.83	0.283
LVM (gr)	153.94 ± 44.20	124.41 ± 30.52	**0.0001***
LVMI (g/m^2)	93.91 ± 22.68	71.69 ± 24.99	**0.0001***
RWT (mm)	0.384 ± 0.06	0.376 ± 0.06	0.243
TAPSE	22.3 ± 2.46	22.6 ± 4.96	0.471
EF (%)	71.1 ± 5.54	71.7 ± 5.38	0.685

*Significant difference ($p < 0.05$). EF, Ejection Fraction; IVSD, Interventricular Septum in Diastole; LAD, Left Atrium Diameter; LVEDD, Left Ventricular End-Diastolic Diameter; LVESD, Left Ventricular End-Systolic Diameter; LVM, Left Ventricular Mass; LVMI, Left Ventricular Mass Index; LVPWT, Left Ventricular Posterior Wall Thickness; RWT, Relative Wall Thickness; TAPSE, Tricuspid Annular Plane Systolic Excursion.

Discussion

Resting heart rate is negatively associated with exercise frequency.[15] We found that the resting heart rate was significantly lower in the dynamic group compared to both the beginner group and the static group. While this finding was expected in the beginner group, it was less anticipated in the static group. This may be explained by exercise frequency, as the static group had a lower training intensity than the dynamic group, although the difference was not statistically significant.

According to Kelley et al.,[16] short-term exercise does not appear to decrease resting systolic and diastolic blood pressure in children and adolescents. Their meta-analysis included participants who trained for up to 36 weeks. In our study, median length of training was 12 months in the dynamic group and 10 months in the static group. In agreement with these findings, we concluded that this duration was insufficient to cause a significant change in blood pressure.

Training-related echocardiographic changes include increases in ventricular cavity size and wall thickness.[17] The most common echocardiographic finding in our study was an increased z-score of IVSD in one-quarter of athletes, consistent with previous studies.[18] The rate of other exercise-related changes ranged between 5.3-11.3% of the athletes. These changes should be considered by physicians during routine evaluations of young athletes to prevent misdiagnosis.

Exercise-induced cardiac remodeling has been predominantly studied in professional athletes, with limited data available on amateur child athletes. It is generally known that endurance sports tend to result in eccentric hypertrophy, whereas strength-based sports lead to concentric hypertrophy.[8,19,20] However, as illustrated by the studies below, inconsistent results have been reported in different pediatric studies. A study conducted by Sulovic et al.[21] found that the frequency of eccentric hypertrophy and concentric hypertrophy was equal among athletes participating in static sports. Similarly, Ayabakan et al.[22] observed that concentric hypertrophy was prominent in swimmers, who are classified as highly dynamic-moderate static athletes. In contrast, Bjerring et al.[23] demonstrated that skiers, who are highly static-moderate dynamic athletes, initially developed concentric remodeling in the pre-adolescent period, followed by the development of eccentric changes with chamber dilatation over time. However, in a follow-up study one year later, the same author found that skiers aged 12-15 years exhibited eccentric remodeling, whereas those aged 15-18 years underwent concentric remodeling.[24] As these findings suggest, both sport type and athlete age may influence cardiac remodeling patterns. Our study population included pre-adolescent and post-adolescent athletes, with a mean age of approximately 12 years, which supports the most recent findings of Bjerring et al.[23] We found that eccentric hypertrophy was the most common remodeling pattern, regardless of sport type, consistent with the findings of Binnetoğlu et al.[7] This type of hypertrophy may be more frequent at younger ages. Interestingly, we found that 7% of beginners exhibited concentric remodeling, a rate similar to that of static athletes, but higher than dynamic athletes. Concentric remodeling in beginners may be associated with underlying hypertensive disease or cardiomyopathies, necessitating further evaluation before granting medical clearance. Additionally, any form of cardiac remodeling was more prevalent in the static dominant group. This may be due to the greater impact of pressure load on the cardiovascular system compared to volume load.

Exercise-induced changes are influenced by length of training, training intensity, and age. Schöffl et al.[25] found a significant increase in the z-scores of IVSD and LVPWT over 27.5 months in climbers and skiers. However, the z-score of LVEDD did not change significantly, and there was no variation in the E/A ratio over time in their study group. Similarly, Agrebi et al.[26] demonstrated that handball players experienced morphological and functional cardiac changes as they grew, trained, and competed regularly, evidenced by increasing values in indexed LVESD, LVEDD, left ventricular mass, and LAD in diastole. In the present study, the z-score of IVSD and LVMI were significantly higher in athletes who had been training for more than 36 months compared to those training for 3-12 months and 12-36 months. This finding suggests that while cardiac remodeling begins to appear between the fourth and sixth month of training, it becomes more pronounced after 36 months.

Additionally, linear regression analysis revealed a significant relationship between length of training and both the z-score of IVSD and z-score of LVEDD. Moreover, the p values for the z-score of LVPWT ($P = 0.061$) and z-score of LVESD ($P = 0.066$) indicated a borderline significant association with length of training. However, in contrast to the study conducted by Agrebi et al.,[26] we did not find a significant relationship between the z-score of LAD and length of training. Our result may be attributed to the diversity of sports in which the participants were engaged.

In this study, parameters such as IVSD, IVSD-z, LVEDD, LVEDD-z, LAD, LVPWT, LV mass, and LV mass index were higher in boys than in girls. Supporting our findings, Forså MI et al.[27] reported that males exhibited greater indexed left ventricular end-diastolic volumes and LV mass index. The authors also found that more males (35%) than females (25%) had a wall thickness above the pediatric reference range. These findings may be explained by the fact that males generally have greater aerobic capacity than females[28] The male advantage in gender-based performance differences may contribute to the higher echocardiographic remodeling parameters.

High frequency of exercise-related adaptive changes in child athletes makes it difficult to distinguish between a child athlete's heart and hypertrophic or dilated cardiomyopathy. In cases of symmetrical left ventricular hypertrophy, athlete's heart should be considered when the following criteria are met:

- Normal left ventricular diastolic function,
- Absence of late gadolinium enhancement (LGE) on cardiac magnetic resonance imaging (MRI),
- Normal electrocardiographic findings,
- Maximum oxygen consumption above 50 mL/kg/min,
- Absence of pathogenic sarcomeric mutation, and
- Reduction in wall thickness after training cessation.[29]

Depending on the sport type, some athletes may meet the dilated cardiomyopathy criteria, particularly those with low EF and LVEDD > 60 mm (or z-score > 2). To differentiate between these conditions, additional evaluations, such as assessing EF improvement after stress echocardiography and confirming the absence of LGE on MRI, should be performed.[30,31]

Limitations

A limitation of this study is its cross-sectional design, conducted at a single center with a relatively small sample size, which restricts the ability to perform thorough subgroup analyses. Therefore, the findings cannot be generalized to the broader population of Türkiye or other ethnic groups.

Due to their amateur status, participants had lower training intensity and total training duration. Additionally, participants, as a whole, engaged in a variety of sports. Although they were examined at the time of their initial application, they were not monitored before or after this evaluation. Lastly, wide age range of the participants may pose another limitation, as age is a factor that influences cardiac remodeling.

Conclusion

Although several studies have investigated exercise-related cardiac changes, this study is important because, to the best of our knowledge, it is the first of its kind conducted in Türkiye with amateur children athletes. In this study, the most common hypertrophic pattern was eccentric in both dynamic and static dominant amateur child athletes, with 12 (13.5%) and 23 (37.1%) cases, respectively. Additionally, pressure load on the cardiovascular system may have a greater impact than volume load, as this study showed that the total cardiac remodeling rate was higher in the static dominant group. We also found a significant positive correlation between the length of training and the z-score of interventricular septal dimension in diastole, as well as the z-score of the left ventricular end-diastolic diameter. It is also noteworthy that while signs of cardiac remodeling begin to appear between the fourth and sixth months of training, they become more pronounced after 36 months.

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