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Is systolic blood pressure an early marker of concentric left ventricular geometry in young rugby athletes as a potential cardiac maladaptation?

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A R T I C L E I N F O

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A B S T R A C T

Background: Long-term exercise training induces various morphological adaptations in the heart. Although concentric left ventricular (LV) geometry is occasionally observed in young athletes, its clinical significance is unclear. This study aimed to investigate the characteristics of young rugby athletes with concentric LV geometry and considered its clinical implications.

Methods and results: This cross-sectional study assessed 120 male collegiate rugby freshmen, with a healthy lifestyle and without a family history, via physical and blood pressure evaluations, resting 12-lead electrocardiography (ECG), echocardiography, and cardiopulmonary exercise testing. The athletes were divided into three groups based on the 4-tiered echocardiographic classification for LV hypertrophy: normal geometry, concentric geometry, and eccentric hypertrophy. Concentric geometry was identified in 11 % of the athletes. No significant differences in anthropometry or exercise capacity were observed between athletes with normal and abnormal geometries. However, athletes with concentric geometry had significantly higher systolic blood pressure (SBP) compared to the other groups. SBP levels were significantly correlated with both LV mass index and concentricity; an SBP ≥136 mmHg could independently predict concentric geometry. In contrast, the ECG criteria for LV hypertrophy showed limited diagnostic accuracy for detecting concentric geometry.

Conclusion: These findings suggest that elevated SBP can serve as an early marker for identifying and managing concentric geometry in young athletes, which potentially represents a mild, previously unrecognized form of hypertensive remodeling.

1. Introduction

Physiological cardiac adaptation, often referred to as “athlete's heart,” which occurs in response to prolonged exercise, is proportional to the level of hemodynamic stress and training duration and frequency and is reversible after detraining [1]. Clinicians should interpret cardiac evaluations in athletes on an individual basis, given that athlete's heart is influenced by factors, such as the specific athletic discipline. Competitive athletes engaged in endurance sports typically exhibit enlarged ventricular and atrial chambers with eccentric left ventricular hypertrophy (LVH) due to the volume overload from high cardiac output. Conversely, athletes who focus primarily on static or isometric exercises exhibit a relative increase in LV wall thickness due to arterial pressure overload, without considerable LVH [1].

Changes in LV geometry and functional adaptation have been observed across sporting disciplines [2–4]. In the general population,

Abbreviations: LV, left ventricular; ECG, electrocardiography; 4 TC, 4-tiered echocardiographic classification; SBP, systolic blood pressure; LVH, left ventricular hypertrophy; 2 TC, 2-tiered classification; CPET, cardiopulmonary exercise testing; LVEDD, LV end-diastolic dimension; LVESD, LV end-systolic dimension; IVSth, thickness of the LV interventricular septum; PWth, thickness of the LV posterior wall; LVM, LV mass; BSA, body surface area; GLS, global longitudinal strain; ROC, receiver operating characteristic; AUC, area under the curve; PPV, positive predictive value; NPV, negative predictive value; LR+, positive likelihood ratio.

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abnormal LV geometry can be detrimental and is associated with a higher risk of morbidity and mortality [5]. This evidence supports the importance of including LV geometry assessment and detection of pathological cardiac structures and functions in echocardiographic screenings for athletes, although the association between adverse outcomes and LV geometry in athletes remains unclear. Echocardiography assesses LV geometry and has traditionally been classified based on a 2-tiered classification (2 TC) [6]. Recently, a 4-tiered classification (4 TC) for LVH has been developed [7], which demonstrates better risk-stratification for adverse cardiovascular events in patents with hypertension and the general population [8,9]. Further categorization using the 4 TC may be beneficial for more accurate articulation of geometrical adaptation [10,11].

Rugby includes various activities that combine moderate-to-high isometric and isotonic elements [12], making rugby players an ideal cohort for investigating athlete's heart. We previously reported an association between cardiac adaptive remodeling and exercise capacity in Japanese collegiate rugby players, aiming to assess athlete's heart in East Asians [13]. Our findings indicated a higher prevalence of concentric LV geometry (remodeling/hypertrophy) after evaluation based on the 4 TC than the 2 TC among these athletes.

Notably, few studies have explored the clinical significance of acquired concentric LV geometry not typically considered pathological, such as hypertrophic cardiomyopathy, in young athletes [14]. Among nonathletic populations, early-onset concentric LV geometry is associated with an elevated risk of coronary heart disease and stroke later in life [15]. Therefore, the present study aimed to investigate the characteristics of young rugby athletes with concentric LV geometry, as determined by the 4 TC, and to consider its clinical implications. The findings of this study are expected to provide novel insights into the cardiovascular risks associated with concentric LV geometry in athletes, potentially yielding more effective screening and prevention strategies in this population.

2. Methods

2.1. Participants

Overall, 120 male freshmen athletes from the Nippon Sport Science University rugby team underwent cardiac evaluation at our institution between 2015 and 2019. Most athletes began their rugby career between the ages of 10 and 13 years and continued training with competitive school and/or community teams. The athletes participated in structured exercise training with the college team for >10 h/week, including both position-specific and common programs [13]. The lifestyle guidance extended to the dormitories during the athletes' college years, including nutritional management.

This prospective, cross-sectional study collected data from the participants, including physical examination, bioelectrical impedance analysis, resting 12-lead ECG, echocardiography, and cardiopulmonary exercise testing (CPET) findings. Resting blood pressure (BP) was measured after a 3-min rest in the seated position with the spine upright using an automatic sphygmomanometer and an appropriately sized cuff and recorded as the average of 3 measurements. Systolic BP (SBP) status was categorized as normal (SBP <120 mm Hg), high normal (SBP 120–129 mm Hg), elevated BP (SBP 130–139 mm Hg), or hypertension (SBP ≥140 mm Hg), in accordance with the guidelines of Japanese Society of Hypertension 2019 [16]. Bioelectrical impedance analysis was performed using InBody S10 (InBody Japan Inc., Tokyo, Japan) to determine body composition, including body fat mass and appendicular skeletal muscle mass. Ten athletes were excluded from this study owing to incomplete examination data. Ultimately, 110 athletes were analyzed (107 Japanese and 3 Polynesian). Echocardiographic left ventricular (LV) geometry was classified according to the 4 TC thresholds (Supplemental Fig. 1). Subsequently, the athletes were divided into three groups based on LV geometry: normal geometry, concentric LV geometry (including remodeling and hypertrophy), and eccentric LVH (Table 1).

This study adhered to the Declaration of Helsinki and was approved by the Institutional Review Board of Showa University Fujigaoka Hospital (approval number 2015099). Written informed consent was obtained from all participants.

2.2. Electrocardiography

Standard 12-lead ECG recording was performed after a brief rest with the athlete in the supine position using the ECG Analysis System (ECG-2550; NIHON KODEN Co., Ltd., Tokyo, Japan). The Sokolow–Lyon (S V1 + R V5/V6 ≥ 3.5 mV) and Peguero–Lo Presti (sum of the amplitude of the deepest S wave in any lead and the S wave in lead V4 ≥ 2.8 mV in men) [17] voltage criteria were used as determinants of ECG-LVH. The former is the most widely used ECG-LVH criterion for athletes [18], whereas the latter is a novel voltage criterion that demonstrates higher sensitivity and similar specificity to the Cornell criterion in patients with hypertension [19].

2.3. Echocardiography

Comprehensive two-dimensional and Doppler echocardiography were performed using digital echocardiography equipment (TUS-A400, Canon Medical Systems, Tochigi, Japan), as described previously [13, 20,21]. Standard measurements were performed according to the guidelines of the American Society of Echocardiography and European Association of Cardiovascular Imaging [6]. Two-dimensional measurements of the left heart included the LV end-diastolic dimension (LVEDD), LV end-systolic dimension (LVESD), thickness of the LV interventricular septum and posterior wall (IVSth and PWth, respectively), LV end-diastolic and end-systolic volumes, LV mass (LVM), and left atrial diameter and volume. All volumes were indexed to the body surface area (BSA). LV ejection fraction was calculated using the

Table 1
Clinical characteristics of echocardiographic geometry groups in collegiate rugby players.

	Normal LV geometry (n = 92)	Eccentric LV hypertrophy (n = 6)	Concentric LV geometry (n = 12)
Age, years	18.5 ± 0.6	18.3 ± 0.5	18.2 ± 0.4
Forward position, n (%)	42 (46)	2 (33)	7 (58)
Height, cm	174 ± 6	175 ± 3	172 ± 5
Weight, kg	83 ± 14	81 ± 7	89 ± 13
Body mass index, kg/m^2	27.4 ± 4.1	26.6 ± 1.7	30.1 ± 4.3
Body surface area, m^2	2.0 ± 0.2	2.0 ± 0.1	2.0 ± 0.1
Appendicular skeletal muscle mass index	9.4 ± 0.8	9.5 ± 0.5	9.6 ± 0.9
% body fat mass, %	19.2 ± 7.4	16.0 ± 6.1	24.2 ± 5.0
Resting heart rate, bpm	72 ± 7	70 ± 14	71 ± 11
Resting blood pressure (systolic), mmHg	126 ± 14[b]	120 ± 7[b]	141 ± 18
Resting blood pressure (diastolic), mmHg	71 ± 12	74 ± 14	80 ± 15
Peak oxygen uptake, mL/min/kg	42.5 ± 8.0	45.5 ± 5.2	40.9 ± 7.1
Electrocardiography			
PR duration, ms	159 ± 820	146 ± 20	153 ± 19
QRS duration, ms	99 ± 8	106 ± 11	100 ± 10
Corrected QT interval, ms	406 ± 17	410 ± 21	402 ± 24
Prevalence of positive Sokolow criterion, n (%)	37 (40)	5 (83)	4 (33)
Prevalence of positive Peguero criterion, n (%)	34 (37)[a]	5 (83)	7 (58)

[a] $p < 0.05$ vs. abnormal LV geometries.
[b] $p < 0.01$ vs. concentric LV geometry.

biplane-modified Simpson's method. Relative wall thickness was defined as two times the PWth at end diastole divided by the LVEDD. LV global longitudinal strain (GLS) was also measured, as described previously [13,20,21].

Phenotypic characterization of LV geometry was based on the 4 TC for LVH (7,10, 11, 13,22]. LVH was defined as LVM/BSA >116 g/m^2. LV geometry was specified by LV concentricity (LVM/LVEDV$^{2/3}$) and further indexed by the LVEDV. The echocardiographic thresholds for increased concentricity and increased LVEDV/BSA were $\geq$ 9.1 g/mL$^{2/3}$ and $\geq$76 mL/m^2, respectively. In the 4 TC, LV geometry was classified according to the thresholds described above: normal geometry, concentric remodeling, concentric LVH (including dilated and non-dilated forms), and eccentric LVH (including dilated and non-dilated forms) (Supplemental Fig. 1).

2.4. Cardiopulmonary exercise testing

CPET was performed, as described previously [13]. Briefly, a symptom-limited incremental exercise test was performed after 4 min of rest. The expired gas was continuously collected and analyzed using an AE-310S gas analyzer (Minato Co., Osaka, Japan). Peak oxygen uptake was defined as the highest maximum oxygen consumption value achieved during peak exercise.

2.5. Statistical analyses

Data were analyzed using commercial software (JMP Pro, version 16.0; SAS Institute Inc., Cary, NC, USA). All data are expressed as the mean ± standard deviation, unless otherwise indicated. Differences between categorical variables were assessed using the chi-squared or Fisher's exact tests. Continuous variables were compared among the three groups using a one-way analysis of variance, followed by Tukey's honest significant difference test. Pearson's simple linear regression analysis was used to determine the correlation coefficients between the two parameters. Univariate and multivariate logistic analyses were employed to assess the independent predictive factors for concentric geometry. $P < 0.05$ was considered statistically significant.

The cut-off values of SBP for detecting concentric LV geometry were defined as the values yielding the maximum area under the receiver operating characteristic (ROC) curve, denoted by the area under the curve (AUC). To estimate the diagnostic ability of the ECG-LVH criteria for echocardiographic abnormal LV geometries, the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and positive likelihood ratio (LR+) were calculated.

3. Results

3.1. Anthropometry, blood pressure, and exercise capacity in young rugby athletes with normal and abnormal geometries

The young athletes included in this study had no history of overt hypertension prior to college, no family history of cardiomyopathy and normal results on physical examination. According to the 4 TC, 84 % of the young rugby athletes had normal LV geometry, 11 % had concentric geometry (hypertrophy, $n = 8$; remodeling, $n = 4$), and 5 % had eccentric LVH (Table 1 and Supplemental Fig. 1). The three athletes of Polynesian origin were assigned to the normal category.

No significant differences were observed in the distribution of field positions, anthropometric parameters, and exercise capacity among the three geometry groups (Table 1). However, the %fat mass of the concentric geometry group was greater than that of the normal geometry ($p = 0.07$) and eccentric LVH ($p = 0.06$) groups. The resting SBP was significantly higher in athletes with concentric geometry than in those with normal geometry and eccentric LVH ($p < 0.01$, respectively). The athletes were classified based on SBP levels according to the guidelines of Japanese Society of Hypertension 2019 [16]. The distribution of the athletes is shown in Fig. 1A. The SBP was >130 mmHg (more than elevated BP) in 67 % of athletes with concentric geometry, whereas none of the athletes with eccentric LVH had an SBP >130 mmHg (Fig. 1B).

3.2. Electrocardiography findings in young rugby athletes with normal and abnormal geometries

Based on the international recommendations for electrocardiographic interpretation in athletes [18], no athlete, except one, exhibited abnormal ECG findings. In the athlete with inferolateral T-wave inversion, echocardiography showed normal cardiac structure and function and normal geometry per the 4 TC. PR and QRS durations and the corrected QT interval did not differ among the three groups (Table 1). The eccentric LVH group showed a higher proportion of athletes who tested positive for the Sokolow–Lyon and the Peguero–Lo Presti criteria among the three groups. The proportion of athletes who were positive for the Peguero–Lo Presti criteria was significantly lower in the normal geometry group than in the abnormal geometry groups ($p < 0.05$). Diagnostic evaluation of the ECG-LVH criteria for detecting abnormal LV geometries using sensitivity, specificity, PPV, NPV, and LR+ (Supplemental Table 1) showed that the Sokolow–Lyon and Peguero–Lo Presti criteria demonstrated similar diagnostic performance for detecting eccentric LVH and were probably adequate for screening (Sokolow–Lyon, sensitivity 83.3 %, specificity 61.7 %; Peguero–Lo Presti, sensitivity 83.3 %, specificity 60.7 %). However, although the Peguero–Lo Presti criteria were marginally superior to the Sokolow–Lyon criteria, neither was clinically sufficient for detecting concentric geometry (Sokolow–Lyon, sensitivity 33.3 %, specificity 58.4 %; Peguero–Lo Presti, sensitivity 58.3 %, specificity 60.4 %).

3.3. Echocardiographic findings and factors contributing to concentric left ventricular geometry in young rugby athletes

The echocardiographic study revealed that athletes with eccentric LVH exhibited the largest absolute and indexed LVEDD and LVESD among the three groups, with values significantly larger than those in the normal geometry group ($p < 0.001$, respectively; Table 2). The indexed LVEDV was significantly smaller in the concentric geometry group than in the eccentric LVH group ($p < 0.01$). Although LV wall thickness was significantly higher in the concentric geometry group than in the normal geometry group (IVSth, $p < 0.05$; PWth, $p < 0.001$), no athlete had an LV wall thickness >13 mm. All athletes exhibited normal LV ejection fraction, E/A, and E/e'. GLS did not significantly differ among three groups.

We investigated the correlations among 4 TC components, LVM/BSA, LV concentricity, %fat mass, SBP, and measurements derived from the ECG-LVH criteria (Table 3). Although the associations were weak, LVM/BSA was significantly correlated with both SBP ($r = 0.247$, $p < 0.01$) and the measurements derived using the ECG-LVH criteria (the Sokolow–Lyon, $r = 0.221$, $p < 0.05$; the Peguero–Lo Presti, $r = 0.226$, $p < 0.05$). Conversely, LV concentricity was significantly associated with %fat mass ($r = 0.315$, $p = 0.001$) and SBP ($r = 0.306$, $p = 0.001$). ROC curve analysis identified a cut-off SBP value of 136 mmHg for detecting concentric LV geometry (AUC = 0.760, $p = 0.002$; Fig. 1C). The frequency of athletes with an SBP ≥136 mmHg was significantly higher in the concentric geometry group than in the other two groups. Logistic regression identified prognostic factors for concentric geometry among %fat mass ≥25 %, SBP ≥136 mmHg, and the ECG-LVH criteria (Supplemental Table 2). Multivariate analysis revealed that SBP was significantly associated with concentric LV geometry in the young athletes (odds ratio, 6.67; 95 % coefficient interval, 1.79–28.3; $p = 0.005$).

3.4. Sub-analysis in young rugby athletes with abnormal LV geometries

We further compared athletes with concentric remodeling,

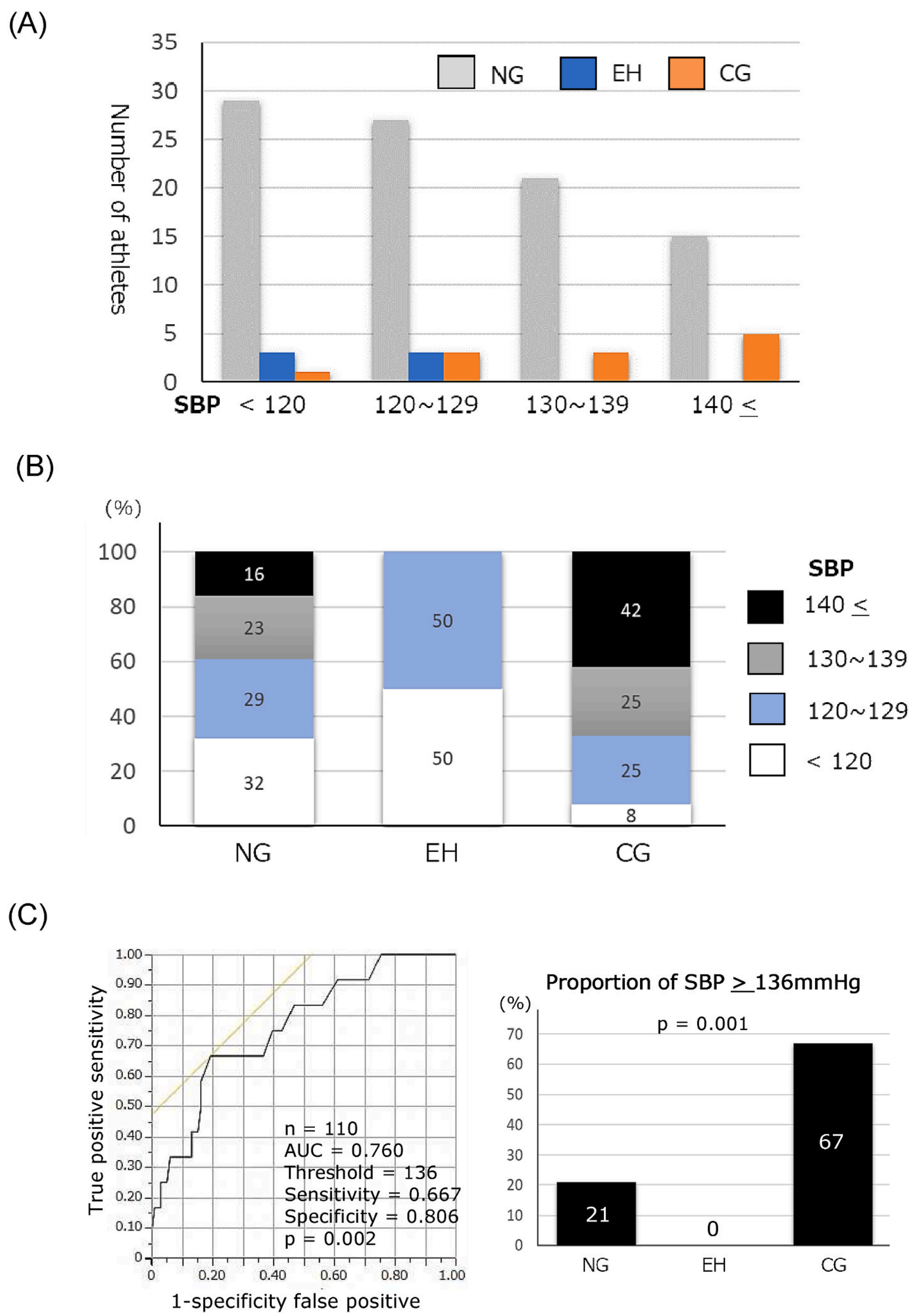

Fig. 1. Distribution of systolic blood pressure (SBP) status in collegiate rugby athletes. (A) Number of athletes in categorical BP status according to the guidelines of the Japanese Society of Hypertension 2019 [22]. (B) Proportion of categorical BP status in athletes with normal and abnormal LV geometry. (C) Left, ROC analysis and cut-off values of SBP (136 mmHg) for detecting concentric LV geometry. Right, prevalence of athletes with an SBP ≥136 mmHg in each LV geometry. NG, normal geometry; EH, eccentric hypertrophy; CG, concentric geometry.

concentric LVH, and eccentric LVH (Supplemental Table 3). In this sub-analysis, athletes with concentric remodeling exhibited higher SBP and significantly greater %fat mass compared to those with eccentric LVH ($p = 0.06$ and $p < 0.05$, respectively). Similarly, SBP and %fat mass in athletes with concentric LVH were slightly higher than those in the eccentric LVH group. Notably, LV concentricity showed a stronger correlation with both %fat mass ($r = 0.695$, $p = 0.001$) and SBP ($r = 0.563$, $p = 0.015$) compared to the correlations observed in the entire athlete cohort. These findings further indicate that the development of abnormal LV geometries in young athletes probably differs between the eccentric and concentric phenotypes.

Regarding echocardiographic parameters (Supplemental Table 3), the LV structure in concentric LVH likely represents the intermediate stage between eccentric LVH and concentric remodeling. However, the absolute and indexed LVM and left atrial diameter and volume were the largest in athletes with concentric LVH among the groups with abnormal LV geometry. Eccentric LVH with normal cardiac function is traditionally considered a benign adaptation to athletic training. In contrast, the development of concentric geometry appears to be influenced by BP and adiposity, in addition to high-intensity exercise training.

4. Discussion

In the present study, we investigated the specific characteristics of young athletes with concentric geometry identified by the 4 TC. Anthropometric measurements and exercise capacity did not

Table 2
Echocardiographic measurements in collegiate rugby players with normal and abnormal LV geometries.

	Normal LV geometry (n = 92)	Eccentric LV hypertrophy (n = 6)	Concentric LV geometry (n = 12)
LVEDD, mm	52.3 ± 3.1	57.7 ± 1.4[c]	56.2 ± 3.1[c]
LVEDD/BSA, mm/m²	26.3 ± 1.9	29.3 ± 1.9[c]	27.6 ± 2.1
LVESD, mm	32.9 ± 3.1[b]	37.5 ± 0.8	34.1 ± 3.0
LVESD/BSA, mm/m²	16.6 ± 1.8[b]	19.0 ± 0.9[a]	16.8 ± 1.8
IVSth, mm	10.2 ± 0.8[a]	10.7 ± 0.8	10.9 ± 0.8
PWth, mm	10.0 ± 0.9	10.3 ± 0.8	11.1 ± 0.7[c]
RWT	0.38 ± 0.04	0.36 ± 0.03	0.40 ± 0.03
LVEDV, ml	150 ± 25	167 ± 19	141 ± 30
LVEDV/BSA, mL/m²	75.1 ± 10.1	84.7 ± 9.4	68.8 ± 12.6[b]
LVESV, ml	54.4 ± 10.9	59.8 ± 6.4	51.8 ± 12.3
LVESV/BSA, mL/m²	27.2 ± 4.9	30.3 ± 3.2	25.3 ± 4.9
LVM, g	198 ± 29	245 ± 16[c]	260 ± 38[c]
LVM/BSA, g/m²	98.4 ± 10.6	122.0 ± 4.1[c]	125.8 ± 14.4[c]
LAD, mm	36.0 ± 3.9	37.7 ± 3.5	38.3 ± 3.0
LAV, ml	56.8 ± 13.3	60.0 ± 16.9	58.0 ± 16.7
LAV/BSA, mL/m²	28.4 ± 6.3	30.2 ± 7.5	28.2 ± 7.1
LVEF, %	64.0 ± 4.6	64.3 ± 2.7	64.1 ± 4.2
E/A	2.3 ± 0.5	2.4 ± 0.5	2.2 ± 0.6
E/e'	6.2 ± 1.5	5.9 ± 1.1	6.5 ± 1.1
GLS, %	−17.8 ± 1.3	−18.0 ± 1.3	−17.6 ± 1.3

BSA, body surface area; GLS, global longitudinal strain; IVSth, thickness of the interventricular septum; LAD, left atrial dimension; LAV, left atrial volume; LVEDD, left ventricular (LV) end-diastolic dimension; LVEDV, end-diastolic volume; LVEF, LV ejection fraction; LVESD, LV end-systolic dimension; LVESV, LV end-systolic volume; LVM, LV mass; PWth, posterior wall thickness; RWT, relative wall thickness.

[a] $p < 0.05$ vs. concentric geometry.
[b] $p < 0.01$ vs. eccentric hypertrophy.
[c] $p < 0.001$ vs. normal geometry.

Table 3
Pearson's Correlation Analysis of 4 TC and %Fat Mass, SBP, and Measurements derived from ECG-LVH Criteria.

	LVMI		LV Concentricity	
	Correlation coefficient	p	Correlation coefficient	p
% body Fat mass	0.076	0.430	0.315	0.001
SBP	0.247	0.009	0.306	0.001
Measurements from Sokolow's formula	0.221	0.020	0.018	0.854
Measurements from Peguero's formula	0.226	0.018	0.111	0.249

Formula of ECG-LVH criteria: Sokolow–Lyon, S V1 + R V5/V6 (mV); and Peguero–Lo Presti, sum of the amplitude of the deepest S wave in any lead and the S wave in lead V4 (mV).
LVMI, LV mass index; SBP, systolic blood pressure.

significantly differ between athletes with normal and abnormal geometries. However, athletes with concentric geometry had significantly higher SBP levels compared with those in the other two groups. Furthermore, this is the first study to demonstrate a relationship between SBP levels and both LVM index and LV concentricity, components of the 4 TC. An SBP >136 mmHg was a prognostic factor for concentric geometry in young rugby athletes, suggesting a potential association between elevated SBP and concentric LV geometry, with important implications for the cardiovascular assessment of young athletes.

4.1. Variability in left ventricular geometry across different athletic populations

The extent and nature of cardiac adaptation vary widely based on age, sex, ethnicity, training status, and sport type [1]. LV geometry provides a more detailed assessment of LV morphological changes across different sports. Utomi et al. [2] reported that normal LV geometry, as classified by the 2 TC, was common among male athletes participating in both dynamic and static sports, with none showing concentric geometry. In contrast, Finocchiaro et al. [3] found that 12 % of male athletes engaged in dynamic, static, or mixed training exhibited concentric geometry. Cross-sectional studies of active professional American football players have reported a 23 % incidence rate of LVH, predominantly concentric geometry [23]. Similarly, a 24 % prevalence of concentric LVH was observed in collegiate football players [24]. In a study using the 4 TC [11], 4.3 % of elite male cyclists had concentric geometry and 34.7 % had eccentric LVH, whereas sub-elite cyclists or non-athletes exhibited no concentric geometry. Among middle-aged, male non-elite endurance runners, the 4 TC classified 28 % with concentric geometry and 13 % with eccentric LVH [10]. Additionally, professional English rugby players in their late 20s showed a 3.7 % prevalence of concentric geometry and 16.3 % of eccentric LVH [22]. These 4 TC studies largely derived their data from Caucasian athletes. In our study of predominantly Japanese collegiate rugby athletes, 16 % of male freshman rugby players had abnormal geometry, with 11 % having concentric geometry and 5 % eccentric LVH.

The varying prevalence of concentric LV geometry across different age groups, ethnicities, and sports disciplines highlights the importance of investigating the underlying factors that contribute to its development.

4.2. Concentric left ventricular geometry and blood pressure in athletes

Eccentric LVH with normal cardiac function is traditionally considered a form of benign adaptation in athletes, whereas the implications of acquired concentric LV geometry remain less understood.

Baggish et al. conducted studies on concentric LVH, as determined by the 2 TC, in American football players [14,24–28]. They reported a higher prevalence of concentric LVH among American football players, particularly linemen, who exhibited this condition more frequently than non-linemen (83 % vs. 8 %) [28]. Concentric LVH development was associated with weight gain, intraseasonal changes in SBP, and absolute postseason changes in SBP [26,28]. This pattern of concentric LVH among linemen has been confirmed in several distinct longitudinal collegiate cohorts [25]. Additionally, the study revealed that Black athletes were associated with acquired concentric LVH [27], indicating that the ethnic background is a crucial factor in understanding cardiac adaptation to exercise [1,29].

In a study of middle-aged, Caucasian, male endurance athletes using the 4 TC [10], those with concentric geometry were significantly older and had marginally yet significantly higher SBP levels than the other geometric categories, despite being normotensive. Our study, which focused predominantly on Japanese athletes in their late teens, found that SBP levels were significantly higher in athletes with concentric geometry than those in the other two groups. We also identified a significant association between SBP levels and LV concentricity in the 4 TC. Therefore, this suggests that elevated SBP, even within the higher range of normal BP, may serve as a key contributing and prognostic factor for concentric geometry in athletes, irrespective of age, ethnicity, or sport. However, the two ECG-LVH criteria used in this study did not effectively predict concentric geometry.

The association between acquired concentric LV geometry and outcomes in young athletes remains unclear, although in young nonathletic populations, concentric geometry is associated with increased cardiovascular risks later in life [15]. The development of concentric LV geometry, potentially influenced by elevated BP or hypertension, may be more pathological than adaptive in response to intense training, although this concept remains hypothetical.

4.3. Study limitations

This study has some limitations. First, the cross-sectional design limited our ability to fully understand the detailed mechanisms underlying remodeling processes and the natural progression of LV geometric changes within populations [30]. Although our results and those of previous studies suggest that elevated SBP levels are a key determinant in the development of concentric geometry, even in young athletes, other complex pathophysiological factors, such as sleep-disordered breathing, may also play a role [31,32]. Second, this study was conducted with a selected cohort of predominantly male Japanese rugby athletes. As sports discipline, ethnicity, and sex significantly influence the development of athlete's heart, further studies involving a larger and more diverse group of athletes are necessary to comprehensively evaluate concentric geometry. Third, SBP assessment was based on a single measurement during cardiac screening, which may introduce variability. It was not possible to distinguish whether the elevated BP observed represented essential hypertension, white-coat hypertension, or secondary hypertension, although the athletes reported no prior history of overt hypertension before entering college. We also did not investigate the frequency of intake of non-steroidal anti-inflammatory drugs (NSAIDs) and/or unregulated energy drinks, which can lead to arterial stiffening and hypertension. Fourth, there is potential confusion regarding the concept of LV concentric geometry. While the classification of dilated-concentric LVH has been recognized in previous studies, its application in this specific context may be contentious. Our approach to categorize the LV geometry in the present study was necessitated by the relatively small sample size, which restricted the feasibility of analyzing the subgroups independently. Despite this limitation, we believe that the present study offers valuable insights into the associations between SBP and LV concentricity in athletes. Future studies with larger cohorts and more refined classification methods are needed to further clarify the complex spectrum of LV remodeling in athletic populations. Finally, the lack of follow-up prevented us from determining the long-term prognosis of abnormal LV geometry. However, no reports exist of adverse cardiac events during collegiate life from team doctors and trainers.

5. Conclusions

The development of concentric LV geometry appears to be influenced not only by exercise training at high intensities, including isometric components, but also by elevated BP. Thus, concentric LV geometry athletes may indicate a mild, previously unrecognized form of hypertensive LV remodeling with potential adverse prognostic implications. Early detection of this condition can serve as an effective preventive measure against future cardiovascular complications in young athletes. The echocardiographic 4 TC for LV geometry provides valuable insights into subclinical cardiovascular risks.

Our findings highlight the importance of elevated SBP as a key marker for the early detection and management of concentric LV geometry in young athletes. Team physicians and cardiologists should remain vigilant for the presence of concentric LV geometry in young, at-risk athletes. Regular BP monitoring and targeted interventions may enhance long-term cardiovascular health outcomes in this population.

CRediT authorship contribution statement

Yoshitaka Iso: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hitomi Kitai:** Methodology, Investigation, Formal analysis, Data curation. **Megumi Kubota:** Investigation, Data curation. **Miki Tsujiuchi:** Investigation, Data curation. **Sakura Nagumo:** Investigation, Data curation. **Tsutomu Toshida:** Investigation, Data curation. **Mio Ebato:** Writing – review & editing, Investigation, Data curation. **Hiroshi Suzuki:** Writing – review & editing, Supervision, Data curation.

Disclosures

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

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