Acta Cardiol Sin 2023;39:888–900

Original Article

doi: 10.6515/ACS.202311_39(6).20230306F

General Cardiology

Asian Female Athlete's Heart: The CHIEF Heart Study

Ming-Yueh Liu,[1,2] Pang-Yen Liu,[1,3] Kun-Zhe Tsai,[1,4,5] Joao A. C. Lima,[6] Carl J. Lavie[7] and Gen-Min Lin[1,3]

Background: The cardiac characteristics of Asian female endurance athletes and strength athletes have rarely been investigated.

Methods: This study included 177 Taiwanese young women undergoing military training. Cardiac features were assessed by electrocardiography (ECG) and echocardiography. Then, all participants completed a 3000-meter run to assess endurance capacity, and 89 participants completed a 2-minute push-up test to assess muscular strength. Athletes were those whose exercise performance fell one standard deviation above the mean, and the remaining participants were defined as controls. Multiple logistic regression analysis was used to determine the predictors of the cardiac characteristics of female athletes.

Results: Compared to the female controls, female endurance athletes had a greater QRS duration (ms) (92.12 ± 10.35 vs. 87.26 ± 9.89, p = 0.01) and a higher prevalence of right axis deviation (RAD) (34.9% vs. 11.1%, p < 0.001). There were no differences in any echocardiographic parameters. Greater QRS duration and RAD and lower systolic blood pressure were independent predictors of female endurance athletes [odds ratios (OR) and 95% confidence intervals: 1.05 (1.01-1.09), 2.91 (1.12-7.59) and 0.93 (0.88-0.98), respectively]. Female strength athletes had a greater right ventricular outflow tract (RVOT) (mm) (28.06 ± 3.57 vs. 25.38 ± 3.61, p = 0.007) but revealed no differences in ECG variables. Greater RVOT was the only predictor of female strength athletes [OR: 1.26 (1.05-1.50)].

Conclusions: In Asian military women, a wider QRS duration and the presence of RAD in ECG rather than heart structure and function were found to characterize endurance athletes, whereas a wider RVOT but no ECG features were found to characterize strength athletes.

Key Words: Asian female athlete's heart • Echocardiography • Electrocardiography • Endurance exercise • Strength exercise

Abbreviations	
BSA	Body surface area
CHIEF	Cardiorespiratory Fitness and Health in Eastern Armed Forces
CI	Confidence intervals
ECG	Electrocardiography
LV	Left ventricular
LVMI	Left ventricular mass index
ms	Milliseconds
OR	Odd ratio
Q1	Highest quartile
Q4	Lowest quartile
RAD	Right axis deviation
RV	Right ventricular
RVH	Right ventricular hypertrophy
RVOT	Right ventricular outflow tract
SD	Standard deviation

Received: November 10, 2022 Accepted: March 6, 2023

[1]Department of Internal Medicine, Hualien Armed Forces General Hospital, Hualien; [2]Department of Radiation Oncology, Taichung Armed Forces General Hospital, Taichung; [3]Division of Cardiology, Department of Medicine, Tri-Service General Hospital and National Defense Medical Center; [4]Department of Stomatology of Periodontology, MacKay Memorial Hospital; [5]Department of Dentistry, Tri-Service General Hospital and National Defense Medical Center, Taipei, Taiwan; [6]Departments of Cardiology and Radiology, Johns Hopkins University School of Medicine, Baltimore, MD; [7]John Ochsner Heart and Vascular Institute, Ochsner Clinical School, The University of Queensland School of Medicine, New Orleans, LA, USA.

Corresponding author: Dr. Gen-Min Lin, Department of Internal Medicine, Hualien Armed Forces General Hospital, No. 100, Jinfeng St., Hualien City 970, Taiwan. Tel: 886-3-826-0601 ext. 815920; Fax: 886-3-826-1370; E-mail: farmer507@yahoo.com.tw

INTRODUCTION

Physical activity and fitness have been reported to be strongly associated with cardiovascular health and all-cause mortality.[1-5] Cardiac adaptation to regular exercise, such as greater cardiac mass and diastolic function, has been regarded as a benign process. Highly competitive athletes such as professional basketball and football players have been observed to have greater left ventricular mass index (LVMI) and chamber sizes as measured by transthoracic echocardiography.[6,7] In addition, the characteristics of cardiac remodeling in athletes might differ based on their major exercise modality. Compared to sedentary individuals and strength athletes, endurance athletes were found to have a greater left ventricular diastolic volume.[8] In contrast, some reports revealed that strength athletes had a greater LVMI than endurance athletes and sedentary controls.[9]

It is well known that compared to men, women have a lower cardiac mass adjusted for body size and blood pressure levels.[10] Additionally, women have fewer cardiac structural and hemodynamic changes in response to exercises.[11] In addition to sex differences, prior studies have shown racial/ethnic differences in exercise-induced cardiac structural changes that were more prominent in athletes of African/Afro-Caribbean descent than among Caucasian athletes.[12-14] However, few studies have investigated Asian athletes' hearts.[15] Moreover, as most of the previous studies compared elite athletes to sedentary individuals, it is doubtful that under a given level of physical training, high-performing athletes would still demonstrate more prominent cardiac remodeling than their controls.[15] Military personnel, who receive regular unified training at the base, may be a good population to examine. Among these individuals, "tactical athletes" are those who receive unique training strategies for optimizing occupational physical performance.[16] Therefore, the purpose of this study was to determine the characteristics of Asian female athletes' hearts in a physically active military population in Taiwan.

METHODS

Study population

The data were collected from the ancillary Cardiorespiratory Fitness and Health in Eastern Armed Forces (CHIEF) Heart study, which included 177 military women aged 18-34 years in the Hualien Army Huadong Defense Command Base in Taiwan in January 2020.[17-19] At the base, all military subjects have to complete a 3000-meter run at 6:00 AM and at 16:00 PM led by the Captain at a rate of 120 meters per minute on weekdays. After each run, all military women are required to perform 20 successive push-ups and sit-ups in order within 30 minutes. The training course continued until the end of June. Before the mid-term physical test held on the base in July, all women underwent a health checkup in June, including a self-administered questionnaire for the participants' habits regarding toxic substance use, e.g., cigarette smoking and alcohol intake (active vs. former and never), a 12-lead electrocardiography (ECG) and a transthoracic echocardiography for evaluating their cardiac structure and function in the Hualien Armed Forces General Hospital of Taiwan. In July 2020, 177 women underwent a 3000-meter run to test their endurance capacity. Of these 177 women, 89 (a half from each company) were randomly selected by the base commander of the highest rank to complete a 2-minute push-up test to evaluate their muscular strength capacity and to assess the physical training outcome in each company of the Army base. The flow diagram for participant selection is shown in Figure 1. The study design and protocol of the CHIEF heart study have been described in detail previously.[20-22]

Anthropometric and blood pressure measurements

The body weight and height of each subject were measured in a standing position. Body mass index was calculated as body weight/body height squared (kg/m^2). Body surface area was defined as 0.20247 $\times$ body height (m)$^{0.725}$ $\times$ body weight (kg)$^{0.425}$ based on the Dubois formula.[23] The resting blood pressure of each subject was measured once automatically over the right upper arm in a sitting position by the FT201 blood pressure monitor (Parama-Tech Co., Ltd, Fukuoka, Japan).

Exercise performance measurements

The endurance capacity of each study subject was assessed by the time to complete a 3-kilometer run test. All subjects ran at the Hualien Military Physical Training and Testing Center, which was a flat playground, without carrying any objects. The aerobic run test was performed

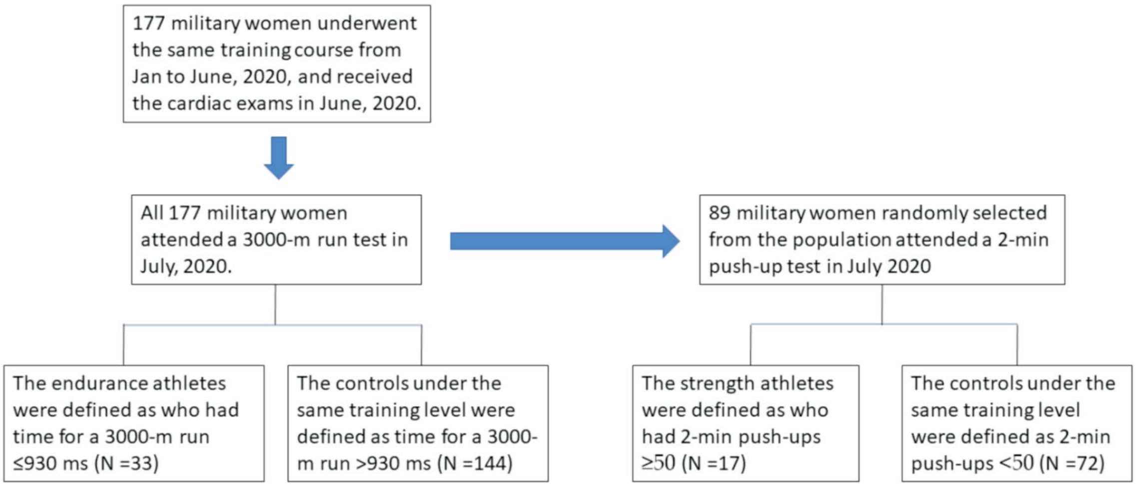

Figure 1. *The flow diagram to select the military female athletes and their controls in the Cardiorespiratory Fitness and Health in Eastern Armed Forces (CHIEF) Heart study in Taiwan.*

outdoors at 16:00 PM and started while the weather was not heavily raining, and the product of relative humidity (%) and outdoor temperature (°C) × 0.1 was lower than 40. The strength capacity of each study subject was assessed by the 2-minute push-up performance on a sponge pad.[17-19] The upward and downward movements of push-ups were scored only if the line of the subject's buttock and back achieved the initial levels set by the infrared red sensors of a computerized score system in the priming period. The push-up test was stopped early when any parts of the body except the subject's hands and foot touched the ground pad sensors before the time (2 minutes) ran out.

ECG and echocardiography measurements

The parameters of 12-lead ECGs were acquired by the Schiller AG CARDIOVIT MS-2015 (Baar, Switzerland). The ECG quality should be visually interpretable; otherwise, a new readable ECG was needed. The ECG analysis was interpreted by two board-certified cardiologists, and the consistency for the ECG diagnosis was 92.6%. Discrepancies between them were solved by consensus. ECG-left ventricular hypertrophy (LVH) was diagnosed according to the Sokolow-Lyon voltage criterion.[23] ECG-left atrial enlargement was defined as a notched P wave ≥ 0.12 seconds or a notch ≥ 0.04 seconds in lead II.[24] ECG-right ventricular hypertrophy (RVH) was defined on the basis of the Sokolow-Lyon voltage criterion[25] or the Myers et al. criteria.[26] Right axis deviation (RAD) was defined if the QRS axis of the ECG frontal leads was > 120°, and left axis deviation was defined when the QRS axis shifted between -30° and -90°.[27] Complete and incomplete right bundle branch block[26] were defined as the rSR' pattern in lead V1 and a S wave wider than the R wave in lead V6 with QRS duration ≥ 120 milliseconds (ms) and < 120 ms, respectively. The pathological ECG findings in female athletes, e.g., prolonged QT interval ≥ 480 ms, have been demonstrated in the International Recommendations for Electrocardiographic Interpretation in Athletes.[27,28]

Cardiac structure and function were evaluated using transthoracic echocardiography (iE33; Philips Medical Systems, Andover, MA, USA) based on the recommendations of the American Society of Echocardiography.[29] All echocardiography was carried out by the same certificated technician. Left ventricular (LV) mass was defined by the latest formula proposed by Devereux et al.[30] Echocardiographic LVH for Southeast Asian young women was defined as LVMI [LV mass adjusted by the body surface area (BSA)][31] ≥ 88 g/m^2 on the basis of prior study findings[21,32] and the EchoNoRMAL study.[33] Right ventricular (RV) hypertrophy in women was defined as an RV wall thickness > 5.0 mm in the parasternal long-axis window.[21] LV diastolic function was assessed by mitral inflow Doppler, and the lateral mitral annulus velocity was assessed by tissue Doppler imaging.[34] RV systolic pressure was evaluated by tricuspid inflow Doppler in a four-chamber window.

Statistical analysis

Military athletes were those who had a better exercise performance falling one standard deviation (SD) above the mean (16%). The control individuals were the remaining physically active women who did not achieve the level of high performance in each exercise (84%). Demographic, 12-lead ECG and echocardiographic features of military athletes and controls were revealed as numbers (percentage) for categorical variables and mean ± SD for continuous variables. Categorical variables were compared by the chi-square test or Fisher's exact test, and continuous variables were compared using analysis of variance. To avoid possible bias of uneven distributions of ECG and echocardiographic variables relative to each physical performance and misclassifications, the cardiac characteristics were also compared between those with the highest quartile (Q1) physical performance and those with the lowest quartile (Q4) physical performance. Multiple logistic regression analysis was used to determine the independent echocardiographic and ECG predictors of female tactical athletes in each exercise category. The covariates adjusted in the multiple logistic regression model include age, body mass index and systolic blood pressure, which are well-known covariates for both cardiac structural remodeling and physical performance, and the cardiac variables, the outcome of interest in this study, which reveal a statistical difference between military athletes and their controls. A two-tailed value of $p < 0.05$ was considered significant. All analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC, USA). This study protocol was reviewed and approved by the Institutional Review Board of the Mennonite Christian Hospital (No. 16-05-008) in Hualien of Eastern Taiwan, and written informed consent was obtained from all participants. In addition, all methods were carried out in accordance with relevant guidelines and regulations.

RESULTS

Clinical characteristics and laboratory findings

As shown in Table 1, 33 (18.6%) military women who completed a 3000-meter run test less than 930 secs were classified as endurance athletes, and the remain-

Table 1. Clinical characteristics of the female athletes and their controls in the 3000-m run test and in the 2-min push-up test

Clinical characteristics	Participants attended the 3000-m run test (N = 177)			Participants attended the 2-min push-up test (N = 89)		
	Endurance athletes (≤ 930 sec) (N = 33)	Endurance controls (> 930 sec) (N = 144)	p value	Strength athletes (≥ 50 times) (N = 17)	Strength controls (< 50 times) (N = 72)	p value
Age (years) (Range: min-max)	23.33 ± 1.89 (20-27)	24.24 ± 3.26 (18-30)	0.12	23.29 ± 3.19 (20-30)	24.74 ± 3.37 (20-34)	0.11
Height (cm)	159.13 ± 4.16	160.77 ± 5.26	0.09	159.84 ± 7.51	160.70 ± 4.59	0.54
Weight (kg)	55.80 ± 6.65	59.79 ± 8.87	0.01	60.43 ± 9.84	59.21 ± 8.22	0.59
Body mass index (kg/m^2)	22.01 ± 2.33	23.10 ± 3.02	0.06	23.55 ± 2.67	22.92 ± 2.99	0.43
Body surface area (m^2)	1.56 ± 0.10	1.63 ± 0.13	0.01	1.63 ± 1.16	1.62 ± 0.12	0.72
Waist circumference (cm)	72.22 ± 5.01	75.48 ± 7.92	0.02	75.94 ± 7.08	75.13 ± 7.78	0.69
Systolic blood pressure (mmHg)	100.24 ± 9.90	107.39 ± 10.68	0.001	108.71 ± 13.750	105.01 ± 9.71	0.19
Diastolic blood pressure (mmHg)	61.06 ± 6.18	64.24 ± 9.15	0.06	63.71 ± 9.19	63.90 ± 6.71	0.92
Blood test						
Creatinine (mg/dL)	0.69 ± 0.09	0.68 ± 0.08	0.67	0.68 ± 0.09	0.69 ± 0.08	0.94
Total cholesterol (mg/dL)	172.27 ± 32.26	161.68 ± 25.70	0.04	175.94 ± 26.79	165.85 ± 24.59	0.13
HDL-C (mg/dL)	62.15 ± 11.87	58.97 ± 11.03	0.14	60.06 ± 10.53	61.96 ± 11.69	0.54
LDL-C (mg/dL)	94.33 ± 23.48	88.25 ± 20.37	0.13	95.71 ± 19.85	91.35 ± 20.43	0.42
Triglycerides (mg/dL)	56.48 ± 14.93	64.95 ± 34.46	0.17	82.18 ± 44.47	63.94 ± 31.01	0.04
Fasting glucose (mg/dL)	87.70 ± 7.84	91.39 ± 7.29	0.01	92.59 ± 10.03	91.22 ± 7.56	0.53
Hemoglobin (g/dL)	13.23 ± 0.97	12.85 ± 1.05	0.06	12.96 ± 1.31	12.83 ± 1.10	0.66
Current cigarette smoking	4 [12.1]	33 [22.9]	0.16	4 [23.5]	12 [16.7]	0.73
Total training years*	5.33 ± 1.89	6.24 ± 3.26	0.12	5.59 ± 3.19	6.74 ± 3.37	0.11
Total training hours*	1920.12 ± 684.44	2245.35 ± 1176.77	0.12	1905.88 ± 1150.90	2425.00 ± 1214.43	0.11
Exercise performance						
3000-m running (secs)	899.85 ± 46.27	1070.26 ± 116.78	< 0.001	1026.73 ± 136.00	1042.19 ± 115.76	0.65
2-min push-ups (numbers)	38.94 ± 13.27	35.07 ± 12.06	0.25	54.65 ± 4.66	31.01 ± 8.80	< 0.001

Continuous variables are expressed as mean ± SD (standard deviation), and categorical variables as n [%].
HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.
* Time were calculated after the enlist.

ing 144 military women were defined as the controls (81.4%). Of the 89 randomly selected military women for a 2-minute push-up test, 17 (19.1%) military women were defined as strength athletes who could perform more than 50 push-ups, and the remaining 72 (80.9%) military women were defined as controls. Endurance athletes and their controls had similar ages and training years. Endurance athletes had a lower fasting glucose, systolic blood pressure and waist circumference and a greater total cholesterol. Endurance athletes and their controls had similar 2-minute push-up numbers (38.9 ± 13.3 vs. 35.1 ± 12.1). On the other hand, strength athletes and their controls had similar age, training years after the enlistment, anthropometric indices, hemodynamic variables and time for a 3000-m run test (1026.7 ± 136.0 sec vs. 1042.6 ± 115.8 sec) and higher plasma triglycerides. As shown in Supplemental Table 1, the clinical profiles between those who did and did not undergo the 2-minute push-up test were similar. In addition, as shown in Supplemental Table 2, of the 89 women who underwent both exercise tests, there were only 5 women defined as athletes in both exercise tests and characterized by a relatively younger age and a higher total cholesterol than women defined as athletes in only the endurance exercise test and those defined as controls in the two tests.

ECG findings

As shown in Table 2, endurance athletes had a longer QRS duration (92.1 ± 10.4 ms vs. 87.3 ± 9.9 ms) and a higher prevalence of RAD (34.9% vs. 11.1%) than the endurance controls, whereas the ECG features were similar between the two groups. In addition, there were no pathological ECG findings for athletes, such as complete left bundle branch block, severe atrioventricular block, or Brugada Type 1 pattern, reported in the study participants, except that there were merely 4 women in the endurance control group and 3 women in the strength control group with a prolonged QTc. As shown in Supplemental Table 3, the sample defined by the Q1 and Q4 physical levels was small, and thus, most of the comparisons were not significant, and the prevalence of RAD was marginally higher among individuals with greater endurance capacity.

Table 2. Electrocardiographic features of the female athletes and their controls in the 3000-m run test and in the 2-min push-up test

ECG characteristics	Participants attended the 3000-m run test (N = 177)			Participants attended the 2-min push-up test (N = 89)		
	Endurance athletes (≤ 930 secs) (N = 33)	Endurance controls (> 930 secs) (N = 144)	p value	Strength athletes (≥ 50 times) (N = 17)	Strength controls (< 50 times) (N = 72)	p value
Heart rate (beats/min)	67.21 ± 8.27	67.60 ± 10.20	0.84	67.41 ± 9.14	69.43 ± 9.41	0.42
P duration (ms)	99.86 ± 16.21	100.10 ± 13.10	0.92	99.42 ± 13.66	99.62 ± 13.02	0.95
PR interval (ms)	154.96 ± 24.86	150.77 ± 22.38	0.34	145.61 ± 21.48	152.09 ± 18.84	0.21
QRS duration (ms)	92.12 ± 10.35	87.26 ± 9.89	0.01	88.35 ± 6.60	85.14 ± 8.00	0.12
QTc interval (ms)	411.09 ± 23.81	410.58 ± 27.66	0.92	410.41 ± 23.63	412.83 ± 30.98	0.76
QRS axis (degree)	75.06 ± 41.94	67.90 ± 26.34	0.21	76.71 ± 18.15	62.99 ± 32.73	0.10
ECG based LVH (%)	2 [6.1]	3 [2.1]	0.21	1 [5.9]	2 [2.8]	0.52
ECG based RVH (%)	0 [0.0]	3 [2.1]	0.40	0 [0.0]	0 [0.0]	NA
Sinus bradycardia (%)	6 [18.2]	34 [23.6]	0.50	3 [17.6]	11 [15.3]	0.80
Ectopic atrial rhythm (%)	2 [6.1]	4 [2.8]	0.34	0 [0.0]	3 [4.2]	0.39
Left atrial enlargement (%)	4 [12.1]	21 [14.6]	0.71	2 [11.8]	8 [11.1]	0.93
First degree atrioventricular block (%)	2 [6.1]	4 [2.8]	0.34	0 [0.0]	2 [2.8]	0.48
Left axis deviation (%)	2 [6.1]	3 [2.1]	0.21	0 [0.0]	3 [4.2]	0.39
Right axis deviation (%)	13 [34.9]	16 [11.1]	< 0.001	4 [23.5]	7 [9.7]	0.12
Complete right bundle branch block (%)	2 [6.1]	1 [0.7]	0.03	0 [0.0]	0 [0.0]	NA
Incomplete right bundle branch block (%)	0 [0.0]	1 [0.7]	0.63	0 [0.0]	0 [0.0]	NA
QT prolongation (%)	0 [0.0]	1 [0.7]	0.63	0 [0.0]	1 [1.4]	0.62
QTc prolongation (%)	0 [0.0]	4 [2.8]	0.33	0 [0.0]	3 [4.2]	0.39
Inferior T wave inversion (%)	2 [6.1]	6 [4.2]	0.63	0 [0.0]	5 [6.9]	0.26

Categorical variables are expressed as N [%].

ECG, electrocardiography; LVH, left ventricular hypertrophy; NA, not available; RVH, right ventricular hypertrophy.

Transthoracic echocardiographic findings

As shown in Table 3, female endurance athletes and controls had similar cardiac structures and LV function. Strength athletes had a greater RV outflow tract (RVOT) dimension (28.1 ± 3.6 mm vs. 25.4 ± 3.6 mm), aortic root dimension (30.3 ± 3.4 mm vs. 26.7 ± 2.4 mm) and left atrial dimension (33.9 ± 3.6 mm vs. 30.5 ± 4.7 mm) than the controls. As shown in Supplemental Table 4, there were no differences in LVMI, RV wall thickness and LV/RV chamber dimensions in those with time for a run in Q1 versus those with time for a run in Q4. In addition, a greater RVOT and left atrial dimension were found in those with push-ups in Q1 than in those with push-ups in Q4. These findings were in line with those shown in Table 3. The results for comparisons in RVOT and LV end-diastolic dimension indexed by BSA between military female and male athletes, which were obtained from our prior study,[15] are also provided in Supplemental Table 5.

ECG and echocardiographic predictors of female athletes

As shown in Table 4, greater QRS duration, RAD and lower systolic blood pressure were independent predictors of female endurance athletes [odds ratios (OR): 1.05 (95% confidence intervals (CI): 1.01-1.09), 2.91 (95% CI: 1.12-7.59) and 0.93 (95% CI: 0.88-0.98)], whereas there were no associations with endurance athletes in the LVMI or RVOT dimension. However, a greater RVOT dimension was found to be an independent echocardiographic predictor of being a female strength athlete [OR: 1.26 (95% CI: 1.05-1.50)]. No associations with the ECG variables, including RAD and QRS duration, and

Table 3. Echocardiographic features of the female athletes and their controls in the 3000-m run test and in the 2-min push-up test

Echocardiographic characteristics	Participants attended the 3000-m run test (N = 177)			Participants attended the 2-min push-up test (N = 89)		
	Endurance athletes (≤ 930 secs) (N = 33)	Endurance controls (> 930 secs) (N = 144)	p value	Strength athletes (≥ 50 times) (N = 17)	Strength controls (< 50 times) (N = 72)	p value
Aortic valve open (mm), PLAX	18.58 ± 1.80	18.74 ± 2.08	0.67	20.18 ± 1.62	18.53 ± 1.76	0.001
Aortic root dimension (mm), PALX	27.03 ± 2.85	27.79 ± 3.46	0.24	30.29 ± 3.38	26.69 ± 2.40	< 0.001
LV posterior wall (mm), PLAX	7.03 ± 0.63	7.24 ± 0.80	0.17	7.24 ± 0.56	7.10 ± 0.77	0.49
LV internal dimension in diastole (mm), PLAX	44.76 ± 2.71	45.17 ± 3.28	0.50	45.41 ± 3.14	44.47 ± 2.87	0.23
Interventricular septum (mm), PLAX	7.15 ± 0.71	7.43 ± 0.84	0.07	7.47 ± 0.71	7.25 ± 0.85	0.32
RV wall thickness (mm), PLAX	4.33 ± 0.53	4.30 ± 0.59	0.80	4.47 ± 0.71	4.32 ± 0.44	0.33
RV outflow tract dimension in diastole (mm), PLAX	25.85 ± 3.49	25.88 ± 4.01	0.96	28.06 ± 3.57	25.38 ± 3.61	0.007
Left atrial dimension (mm), PLAX	31.94 ± 5.50	31.56 ± 4.06	0.64	33.94 ± 3.64	30.53 ± 4.71	0.006
LV mass (gm)	99.20 ± 16.00	105.57 ± 20.94	0.10	106.58 ± 18.29	99.90 ± 19.13	0.19
LV mass index (gm/m^2)	63.16 ± 8.42	64.56 ± 10.60	0.48	65.09 ± 8.16	61.30 ± 9.14	0.12
LV hypertrophy	1 [3.0]	6 [4.2]	0.76	0 [0.0]	2 [2.8]	0.48
RV hypertrophy	0 [0.0]	9 [6.3]	0.14	2 [11.8]	2 [2.8]	0.10
LV ejection fraction (%), PLAX	62.39 ± 5.17	61.35 ± 4.50	0.24	63.47 ± 5.19	61.49 ± 5.07	0.15
Aortic regurgitation ≥ mild grade	0 [0.0]	4 [2.8]	0.33	1 [5.9]	2 [2.8]	0.52
Mitral regurgitation ≥ mild grade	25 [75.8]	105 [72.9]	0.73	14 [82.4]	62 [86.1]	0.69
Pulmonary regurgitation ≥ mild grade	21 [63.6]	93 [64.6]	0.91	12 [70.6]	54 [75.0]	0.70
Tricuspid regurgitation ≥ mild grade	26 [78.8]	120 [83.3]	0.53	15 [88.2]	69 [95.8]	0.22
RV systolic pressure (mmHg)	26.82 ± 5.72	27.36 ± 3.89	0.51	27.82 ± 4.20	27.69 ± 3.53	0.89
E-wave velocity (cm/sec)	93.26 ± 13.35	93.42 ± 17.65	0.96	91.41 ± 10.77	96.58 ± 16.12	0.21
A-wave velocity (cm/sec)	51.08 ± 8.60	49.85 ± 11.05	0.54	52.52 ± 11.29	49.62 ± 9.58	0.28
Mitral inflow E/A ratio	1.87 ± 0.40	1.94 ± 0.49	0.44	1.80 ± 0.37	2.01 ± 0.51	0.11
E′ velocity (cm/sec)	17.60 ± 3.64	17.91 ± 3.57	0.65	17.80 ± 3.94	19.05 ± 3.96	0.24
A′ velocity (cm/sec)	8.64 ± 2.15	8.36 ± 2.37	0.53	9.38 ± 2.37	8.91 ± 2.22	0.46
Lateral mitral annulus E′/A′ ratio	2.16 ± 0.72	2.29 ± 0.72	0.34	2.02 ± 0.77	2.25 ± 0.69	0.24

Continuous variables are expressed as mean ± SD (standard deviation), and categorical variables as N [%].
LV, left ventricle; RV, right ventricle; PLAX, echocardiographic parasternal long axis view; PSAX, echocardiographic parasternal short axis view.

Table 4. Multiple logistic regression analysis for the female endurance and strength athletes

Characteristics	Tactical endurance athletes (N = 177)			Tactical strength athletes (N = 89)		
	OR	95% CI	p value	OR	95% CI	p value
Age	0.93	0.80-1.08	0.30	0.87	0.71-1.07	0.17
Body mass index	0.96	0.81-1.14	0.64	0.97	0.75-1.24	0.78
Systolic blood pressure	0.93	0.88-0.98	0.009	1.04	0.99-1.11	0.14
Right axis deviation	2.91	1.12-7.59	0.02	2.68	0.46-15.55	0.27
QRS duration	1.05	1.01-1.09	0.02	1.05	0.96-1.14	0.30
LV mass index	0.97	0.92-1.01	0.14	1.06	0.99-1.14	0.12
RV outflow tract dimension	1.03	0.93-1.14	0.64	1.26	1.05-1.50	0.01

Data are presented as odds ratios (OR) and 95% confidence intervals (CI) using multiple logistic regression.
LV, left ventricle; RV, right ventricle.

LVMI were found for female strength athletes. The multiple logistic regression analysis showed no associations between female athletes and echocardiographic LVH in Supplemental Table 6.

DISCUSSION

This study is the first report to show the cardiac characteristics in Asian female endurance and strength athletes compared to their controls of military under the same physical training level. The principal findings were that greater QRS duration and the presence of RAD in ECG, rather than cardiac structural parameters, were independent predictors of female endurance athletes. In contrast, female strength athletes may have a greater RVOT than their controls, while no differences in the ECG variables were found.

Cardiac characteristics were rarely compared between elite female athletes and their controls under a similar physical training level.[35-37] In a study by Pelliccia et al.[35] among highly trained White women, female athletes had a greater and greater wall thickness than sedentary controls; additionally, athletes, especially those participating in endurance exercises, had greater cardiac chamber size than sedentary controls. In another study led by Churchill et al.[36] among soccer players in the US, female athletes had a lower LV mass and chamber size and shorter QRS duration than male athletes. The effects of various exercises on the cardiac structural and functional changes in sedentary women have been demonstrated in a study by Cicek et al.;[38] they found that both endurance and strength exercises could increase LV chamber size and LV diastolic function and decrease body weight, lipid profiles, resting heart rate and blood pressure. Mechanisms for exercise-induced structural LVH are due to the elongation of cardiomyocytes, a compensation for chronic hemodynamic overload, and are associated with the renin-angiotensin system.[39,40] In addition, cardiac chamber enlargement has been reported to be associated with volume overload in endurance exercise.[40] In this study, female endurance athletes showed dominant ECG characteristics in RAD and wider QRS duration, rather than in cardiac structural characteristics in LVMI and RV wall thickness, compared to their endurance controls under the same physical training level. These findings might be due to a lower baseline resting hemodynamic level, a less prominent response to endurance exercise, and a smaller body size in women,[10] resulting in less intracardiac pressure and volume loads compared to men. Wider QRS duration and the presence of RAD in ECG, reflecting higher electric forces of LV mass and RV mass, respectively, not accompanied by structural changes to LVH and RVH may be the novel markers for female endurance athletes.

In this study, we found that female strength athletes of military in Taiwan had a greater aortic root, left atrium and RVOT dimension, implying greater stroke volume compared to their controls. However, we did not find greater cardiac mass in strength athletes, which was in contrast to prior study findings that strength exercises may increase cardiac mass more than chamber dimensions.[41] In addition, RV enlargement in athletes has been reported to be associated with higher RV systolic pressure,[42] which was not found in our female strength athletes. Whether these conflicts are related to the specific push-up exercise effect requires further investigation. Notably, there were no differences in the ECG characteristics between strength athletes and their controls.

In a study conducted for Olympic athletes by D'Ascenzi et al.,[43] compared to elite male athletes, elite female athletes had a lower prevalence of ECG-based LVH and RVH. In our prior study of Asian male military athletes in Taiwan,[15] the prevalence of Sokolow-Lyon-based ECG-LVH and RVH were 58% and 15%, respectively, which were both higher than those in Asian female athletes in this study. In addition, the D'Ascenzi et al. study[43] also observed that Olympic female athletes had a greater indexed LV end-diastolic dimension and RVOT than Olympic male athletes, which was consistent with the findings for our Asian female versus male athletes (Supplemental Table 5).[15] In contrast, the study by D'Ascenzi et al.[43] showed that the RVOT dimension index in Olympic female endurance athletes was greater than that in elite female strength athletes, which was inconsistent with our findings for Asian female athletes. Whether these differences are related to racial/ethnic causes should be explored in future research. In summary, Asian female athletes have a normal LV geometry, with relatively greater indexed cavity dimensions than Asian male athletes.

Study strengths and limitations

The strength of the present study was that the study subjects were enrolled from the same military base in Taiwan where the training course was unified. In addition, the daily life of the study military individuals would be very similar, such as diet intake and sleep time, which could restrict the effect of potential confounders. In contrast, only 50.2% of the overall participants were randomly selected to receive the 2-minute push-up test, possibly resulting in a selection bias despite the baseline profiles being similar between those with and without the push-up test. Second, the strength and endurance capacity were assessed by the performance of a 2-minute push-up and time for a 3000-meter run, by which the ECG and echocardiographic predictors might not be the same as those of other elite athletes mastering different exercise modalities. Third, since this is a cross-sectional study, we could not obtain the temporal associations of each exercise performance with clinical outcomes due to the lack of long-term follow-up. Finally, although all echocardiography were performed by the same technician, the echocardiographic measurements were sometimes subjective.

CONCLUSIONS

Our study found that in physically active Asian military women, the presence of RAD and a wider QRS duration in ECG were independent predictors of endurance athletes, whereas a wider RVOT was the only predictor of strength athletes. Possible sex and racial/ethnical differences in Asian female athletes' heart of military observed in this study are slightly different from the elite athletes' heart demonstrated in prior studies, providing the potential normal cardiac features and variants of the specific physically fit population in clinical implications.

DECLARATION OF CONFLICT OF INTEREST

All the authors declare no conflict of interest.

FUNDING

The study was supported by the Medical Affairs Bureau Ministry of National Defense (MND-MAB-D-112182) and Hualien Armed Forces General Hospital (HAFGH-D-112004).

AUTHORS' CONTRIBUTIONS

Ming-Yueh Liu wrote the paper; Kun-Zhe Tsai made statistical analyses; Pang-Yen Liu, Wei-Chun Huang, Joao A. C. Lima and Carl J. Lavie edited the paper and raised critical comments; Gen-Min Lin designed the study and was the principal investigator for the study.

ACKNOWLEDGEMENTS

None.

REFERENCES

1. Kodama S, Saito K, Tanaka S, et al. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality 411 and cardiovascular events in healthy men and women: a meta-analysis. *JAMA* 2009;301:2024-35.
2. Ross R, Blair SN, Arena R, et al. Importance of assessing cardiorespiratory fitness in clinical practice: a case for fitness as a clinical vital sign: a scientific statement from the American Heart Association. *Circulation* 2016;134:e653-99.
3. Lavie CJ, Ozemek C, Carbone S, et al. Sedentary behavior, exercise, and cardiovascular health. *Circ Res* 2019;124:799-815.
4. Yang J, Christophi CA, Farioli A, et al. Association between push-up exercise capacity and future cardiovascular events among active adult men. *JAMA Netw Open* 2019;2:e188341.
5. Mandsager K, Harb S, Cremer P, et al. Association of cardiorespiratory fitness with long-term mortality among adults undergoing exercise treadmill testing. *JAMA Netw Open* 2018;1:e183605.
6. Kim JH, Hollowed C, Liu C, et al. Hypertension, and the emergence of a maladaptive cardiovascular phenotype among US football players. *JAMA Cardiol* 2019;4:1221-9.
7. Engel DJ, Schwartz A, Homma S. Athletic cardiac remodeling in US professional basketball players. *JAMA Cardiol* 2016;1:80-7.
8. D'Andrea A, Riegler L, Morra S, et al. Right ventricular morphology and function in top-level athletes: a three-dimensional echocardiographic study. *J Am Soc Echocardiogr* 2012;25:1268-76.
9. Pluim BM, Zwinderman AH, van der Laarse A, et al. The athlete's heart. A meta-analysis of cardiac structure and function. *Circulation* 2000;101:336-44.
10. Petitto M, Esposito R, Sorrentino R, et al. Sex-specific echocardiographic reference values: the women's point of view. *J Cardiovasc Med (Hagerstown)* 2018;19:527-35.
11. Wooten SV, Moestl S, Chilibeck P, et al. Age- and sex-differences in cardiac characteristics determined by echocardiography in masters athletes. *Front Physiol* 2021;11:630148.
12. Papadakis M, Wilson MG, Ghani S, et al. Impact of ethnicity upon cardiovascular adaptation in competitive athletes: relevance to 446 preparticipation screening. *Br J Sports Med* 2012;46:i22-8.
13. Sheikh N, Sharma S. Impact of ethnicity on cardiac adaptation to exercise. *Nat Rev Cardiol* 2014;11:198-217.
14. Rawlins J, Carre F, Kervio G, et al. Ethnic differences in physiological cardiac adaptation to intense physical exercise in highly trained female athletes. *Circulation* 2010;121:1078-85.
15. Liu PY, Tsai KZ, Lima JAC, et al. Athlete's heart in Asian military males: The CHIEF heart study. *Front Cardiovasc Med* 2021;8:725825.
16. Xu J, Haigney MC, Levine BD, et al. The tactical athlete: definitions, cardiovascular assessment, and management, and "fit for duty" standards. *Cardiol Clin* 2023;41:93-105.
17. Chao WH, Su FY, Lin F, et al. Association of electrocardiographic left and right ventricular hypertrophy with physical fitness of military males: The CHIEF study. *Eur J Sport Sci* 2019;19:1214-20.
18. Lin KH, Chen YJ, Yang SN, et al. Association of psychological stress with physical fitness in a military cohort: The CHIEF study. *Mil Med* 2020;185:e1240-6.
19. Wang SH, Chung PS, Lin YP, et al. Metabolically healthy obesity and physical fitness in military males in the CHIEF study. *Sci Rep* 2021;11:9088.
20. Lin GM, Li YH, Lee CJ, et al. Rationale and design of the cardiorespiratory fitness and hospitalization events in armed 468 forces study in Eastern Taiwan. *World J Cardiol* 2016;8:464-71.
21. Lin GM, Liu K. An electrocardiographic system with anthropometrics via machine learning to screen left ventricular hypertrophy among young adults. *IEEE J Transl Eng Health Med* 2020;8:1800111.
22. Lin GM, Lu HH. A 12-lead ECG-based system with physiological parameters and machine learning to identify right ventricular hypertrophy in young adults. *IEEE J Transl Eng Health Med* 2020;8:1900510.
23. Sokolow M, Lyon TP. The ventricular complex in left ventricular hypertrophy as obtained by unipolar precordial and limb leads. *Am Heart J* 1949;37:161-86.
24. Alpert MA. Electrocardiographic diagnosis of left atrial enlargement. *Arch Intern Med* 1989;149:1161-5.
25. Meng FC, Lin YP, Su FY, et al. Association between electrocardiographic and echocardiographic right ventricular hypertrophy in a military cohort in Taiwan: The CHIEF study: ECG criteria for RVH. *Indian Heart J* 2017;69:331-3.
26. Myers GB, Klein HA, Stofer BE. The electrocardiographic diagnosis of right ventricular hypertrophy. *Am Heart J* 1948;35:1-40.
27. Sharma S, Drezner JA, Baggish A, et al. International recommendations for electrocardiographic interpretation in athletes. *J Am Coll Cardiol* 2017;69:1057-75.
28. Chan CH, Hu YF, Chen PF, et al. Exercise test for patients with long QT syndrome. *Acta Cardiol Sin* 2022;38:124-33.
29. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr* 2015;28:1-39.e14.
30. Devereux RB, Casale PN, Eisenberg RR, et al. Electrocardiographic detection of left ventricular hypertrophy using echocardiographic determination of left ventricular mass as the reference standard. Comparison of standard criteria, computer diagnosis and physician interpretation. *J Am Coll Cardiol* 1984;3:82-7.
31. Du Bois D, Du Bois EF. A formula to estimate the approximate surface area if height and weight be known. *Arch Intern Med* 1916;17:863-71.
32. Wong RC, Yip JW, Gupta A, et al. Echocardiographic left ventricular mass in a multiethnic Southeast Asian population: proposed new gender and age-specific norms. *Echocardiography* 2008;25:805-11.
33. Echocardiographic Normal Ranges Meta-Analysis of the Left Heart Collaboration. Ethnic-specific normative reference values for echocardiographic LA and LV size, LV mass, and systolic function:

The EchoNoRMAL study. *JACC Cardiovasc Imaging* 2015;8:656-65.
34. Yang MC, Liu HK, Tsai CC, et al. Epicardial adipose tissue was highly associated with reduction in left ventricular diastolic function as early as in adolescence. *Acta Cardiol Sin* 2022;38:601-11.
35. Pelliccia A, Maron BJ, Culasso F, et al. Athlete's heart in women. Echocardiographic characterization of highly trained elite female athletes. *JAMA* 1996;276:211-5.
36. Churchill TW, Petek BJ, Wasfy MM, et al. Cardiac structure and function in elite female and male soccer players. *JAMA Cardiol* 2021;6:316-25.
37. Shames S, Bello NA, Schwartz A, et al. Echocardiographic characterization of female professional basketball players in the US. *JAMA Cardiol* 2020;5:991-8.
38. Cicek G, Imamoglu O, Gullu A, et al. The effect of exercises on left ventricular systolic and diastolic heart function in sedentary women: step-aerobic vs core exercises. *J Exerc Sci Fit* 2017;15:70-5.
39. Dostal DE. The cardiac renin-angiotensin system: novel signaling mechanisms related to cardiac growth and function. *Regul Pept* 2000;91:1-11.
40. Fernandes T, Hashimoto NY, Magalhães FC, et al. Aerobic exercise training-induced left ventricular hypertrophy involves regulatory MicroRNAs, decreased angiotensin-converting enzyme-angiotensin II, and synergistic regulation of angiotensin-converting enzyme 2-angiotensin (1-7). *Hypertension* 2011;58:182-9.
41. Morganroth J, Maron BJ, Henry WL, et al. Comparative left ventricular dimensions in trained athletes. *Ann Intern Med* 1975;82:521-4.
42. Mirea O, Corîci OM, Istrătoaie O, et al. Left and right ventricular morphology and function in athletes with elevated pulmonary systolic arterial pressure. *Echocardiography* 2018;35:769-76.
43. D'Ascenzi F, Biella F, Lemme E, et al. Female athlete's heart: sex effects on electrical and structural remodeling. *Circ Cardiovasc Imaging* 2020;13:e011587.

SUPPLEMENTARY MATERIALS

Supplemental Table 1. Clinical characteristics of the military women who attended endurance test only and those who attended both endurance and strength tests

	Military women attended only the endurance test (N = 88)	Military women attended both the endurance and strength tests (N = 89)
Age (years) (Range: min-max)	24.36 ± 3.21 (18-30)	23.29 ± 3.19 (20-30)
Height (cm)	160.32 ± 4.49	159.84 ± 7.51
Weight (kg)	57.61 ± 8.45	60.43 ± 9.84
Body mass index (kg/m^2)	22.40 ± 3.02	23.55 ± 2.67
Body surface area (m^2)	1.60 ± 0.13	1.63 ± 1.16
Waist circumference (cm)	74.21 ± 7.42	75.94 ± 7.08
Systolic blood pressure (mmHg)	106.38 ± 11.11	108.71 ± 13.75
Diastolic blood pressure (mmHg)	64.26 ± 9.79	63.71 ± 9.19
Blood test		
Creatinine (mg/dL)	0.69 ± 0.09	0.68 ± 0.09
Total cholesterol (mg/dL)	160.46 ± 28.04	175.94 ± 26.79
HDL-C (mg/dL)	57.68 ± 11.09	60.06 ± 10.53
LDL-C (mg/dL)	87.47 ± 20.87	95.71 ± 19.85
Triglycerides (mg/dL)	61.68 ± 31.06	82.18 ± 44.47
Fasting glucose (mg/dL)	89.78 ± 7.35	92.59 ± 10.03
Hemoglobin (g/dL)	13.05 ± 0.95	12.96 ± 1.31
Current cigarette smoking	24 [29.6]	4 [23.5]
Total training years	6.36 ± 3.21	6.46 ± 3.35
Total training hours	2288.89 ± 1156.97	2325.84 ± 1206.79
Exercise performance		
3000-m running (seconds)	1030.35 ± 133.07	1026.73 ± 136.00
2-min push-ups (numbers)		54.65 ± 4.66

Continuous variables are expressed as mean ± SD (standard deviation), and categorical variables as n [%].
HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.

Supplemental Table 2. Characteristics of athletes for both exercises, and athletes for only one exercise, and controls for both exercises

Clinical characteristics	Participants who had both endurance and strength data (N = 89)			
	Athletes in both tests (2-min push-ups ≥ 50 & 3000-m run ≤ 930 sec) (N = 5)	Athletes in only one test (2-min push-ups ≥ 50, or 3000-m run ≤ 930 sec) (N = 28)	Controls in both tests (2-min push-up < 50 & 3000-m run > 930 sec) (N = 56)	p value
Age (years) (Range: min-max)	21.00 ± 1.41(20-23)	23.75 ± 2.48(20-30)	24.36 ± 3.06(20-30)	0.07
Height (cm)	156.17 ± 2.86	160.27 ± 7.17	160.50 ± 4.51	0.31
Weight (kg)	53.85 ± 7.69	60.47 ± 8.56	59.69 ± 8.53	0.35
Body mass index (kg/m^2)	22.06 ± 2.98	23.48 ± 2.47	23.16 ± 3.09	0.65
Body surface area (m^2)	1.52 ± 0.11	1.63 ± 0.14	1.62 ± 0.12	0.28
Waist circumference (cm)	71.50 ± 4.12	75.02 ± 6.73	76.12 ± 8.46	0.48
Systolic blood pressure (mmHg)	104.25 ± 13.07	107.50 ± 12.94	105.36 ± 9.76	0.69
Diastolic blood pressure (mmHg)	60.75 ± 1.70	63.13 ± 8.85	63.84 ± 6.68	0.69
Blood test				
Creatinine (mg/dL)	0.66 ± 0.04	0.67 ± 0.08	0.70 ± 0.07	0.36
Total cholesterol (mg/dL)	182.50 ± 21.44	179.21 ± 27.29	162.20 ± 22.47	0.01
HDL-C (mg/dL)	62.50 ± 15.02	64.08 ± 11.02	61.12 ± 11.49	0.58
LDL-C (mg/dL)	101.75 ± 9.91	96.88 ± 22.59	89.64 ± 20.14	0.31
Triglycerides (mg/dL)	67.75 ± 23.28	72.92 ± 39.54	61.16 ± 31.08	0.37
Fasting glucose (mg/dL)	90.50 ± 8.06	91.67 ± 9.57	92.18 ± 7.25	0.90
Hemoglobin (g/dL)	13.82 ± 0.83	12.66 ± 1.07	12.95 ± 1.02	0.10
Current cigarette smoking	0 [0.0]	3 [12.5]	9 [18.0]	0.56
Total training years	3.00 ± 1.41	5.75 ± 2.48	6.36 ± 3.06	0.07
Total training hours	1080.00 ± 509.11	2070.00 ± 896.07	2289.60 ± 1104.84	0.07
Exercise performance				
3000-m running (seconds)	883.75 ± 61.56	985.88 ± 120.53	1077.26 ± 102.01	< 0.001
2-min push-ups (numbers)	59.50 ± 1.00	42.25 ± 12.23	30.98 ± 8.91	< 0.001

Continuous variables are expressed as mean ± SD (standard deviation), and categorical variables as n [%].
HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.

Supplemental Table 3. Multiple logistic regression analysis for echocardiographic left ventricular hypertrophy in the female endurance and strength athletes

Characteristics	Female endurance athletes (N = 177)			Female strength athletes (N = 89)		
	OR	95% CI	p value	OR	95% CI	p value
Left ventricular mass index ≥ 88 g/m^2	6.50	0.30-139.82	0.23	0.00	0.00-0.00	1.00

Data are presented as odds ratios (OR) and 95% confidence intervals (CI) using multiple logistic regression with adjustment for age, body mass index, systolic blood pressure, QRS duration, right axis deviation and right ventricular outflow tract dimension.

Supplemental Table 4. Electrocardiographic features of the military women attended the 3000-m run test and those attended the 2-min push-up test

ECG characteristics	Participants attended the 3000-m run test (N = 177)			Participants attended the 2-min push-up test (N = 89)		
	Q1-performance (< 965 sec) (N = 47)	Q4-performance (≥ 1100 sec) (N = 42)	p value	Q1-performance (> 40 times) (N = 25)	Q4-performance (< 30 times) (N = 28)	p value
Heart rate (beats/min)	66.23 ± 8.96	69.17 ± 10.12	0.15	68.60 ± 9.95	68.93 ± 9.72	0.90
P duration (ms)	100.54 ± 16.96	98.79 ± 11.52	0.57	100.41 ± 12.30	99.30 ± 8.59	0.70
PR interval (ms)	154.11 ± 24.55	151.80 ± 17.60	0.61	148.94 ± 20.10	150.24 ± 20.83	0.81
QRS duration (ms)	90.45 ± 10.32	88.76 ± 6.98	0.37	87.28 ± 8.32	86.14 ± 7.61	0.60
QTc interval (ms)	407.87 ± 22.73	408.67 ± 23.80	0.87	406.00 ± 22.62	417.18 ± 37.04	0.19
QRS axis (degree)	74.91 ± 36.52	65.67 ± 31.74	0.20	75.04 ± 16.12	58.21 ± 31.40	0.02
ECG based LVH (%)	2 [4.3]	0 [0.0]	0.17	1 [4.0]	0 [0.0]	0.28
ECG based RVH (%)	1 [2.1]	1 [2.4]	0.93	0 [0.0]	0 [0.0]	NA
Sinus bradycardia (%)	11 [23.4]	7 [16.7]	0.43	3 [12.0]	3 [10.7]	0.88
Ectopic atrial rhythm (%)	2 [4.3]	1 [2.4]	0.62	1 [4.0]	1 [3.6]	0.93
Left atrial enlargement (%)	7 [14.9]	8 [19.0]	0.56	2 [8.0]	3 [10.7]	0.73
First degree atrioventricular block (%)	2 [4.3]	0 [0.0]	0.17	0 [0.0]	1 [3.6]	0.34
Left axis deviation (%)	2 [4.3]	1 [2.4]	0.62	0 [0.0]	1 [3.6]	0.34
Right axis deviation (%)	15 [31.9]	7 [16.7]	0.09	4 [16.0]	2 [7.1]	0.31
Complete right bundle branch block (%)	2 [4.3]	0 [0.0]	0.17	0 [0.0]	0 [0.0]	NA
Incomplete right bundle branch block (%)	0 [0.0]	0 [0.0]	NA	0 [0.0]	0 [0.0]	NA
QT prolongation (%)	0 [0.0]	0 [0.0]	NA	0 [0.0]	1 [3.6]	0.34
QTc prolongation (%)	0 [0.0]	0 [0.0]	NA	0 [0.0]	2 [7.1]	0.17
Inferior T wave inversion (%)	2 [4.3]	1 [2.4]	0.62	1 [4.0]	2 [7.1]	0.62

Categorical variables are expressed as N [%].

ECG, electrocardiography; LVH, left ventricular hypertrophy; NA, not available; RVH, right ventricular hypertrophy.

Supplemental Table 5. Echocardiographic features of the military women attended the 3000-m run test and those attended the 2-min push-up test

Echocardiographic characteristics	Participants attended the 3000-m run test (N = 177)			Participants attended the 2-min push-up test (N = 89)		
	Q1-performance (< 965 sec) (N = 47)	Q4-performance (≥ 1100 sec) (N = 42)	p value	Q1-performance (> 40 times) (N = 25)	T3-performance (< 30 times) (N = 28)	p value
Aortic valve open (mm), PLAX	18.77 ± 1.93	19.12 ± 2.10	0.41	20.00 ± 1.58	18.14 ± 1.53	< 0.001
Aortic root dimension (mm), PALX	27.26 ± 3.24	29.45 ± 3.56	0.003	29.40 ± 3.35	26.75 ± 2.06	0.001
LV posterior wall (mm), PLAX	7.09 ± 0.74	7.33 ± 0.68	0.10	7.08 ± 0.64	7.04 ± 0.83	0.83
LV internal dimension in diastole (mm), PLAX	44.85 ± 3.07	45.74 ± 3.28	0.19	45.32 ± 3.26	45.18 ± 2.77	0.86
Interventricular septum (mm), PLAX	7.17 ± 0.70	7.57 ± 0.80	0.01	7.40 ± 0.70	7.14 ± 1.04	0.30
RV wall thickness (mm), PLAX	4.27 ± 0.49	4.50 ± 0.69	0.09	4.34 ± 0.64	4.34 ± 0.45	0.99
RV outflow tract dimension in diastole (mm), PLAX	26.04 ± 3.87	26.02 ± 4.03	0.98	27.72 ± 3.50	25.25 ± 4.02	0.02
Left atrial dimension (mm), PLAX	31.91 ± 4.88	32.60 ± 4.22	0.48	33.72 ± 3.44	29.93 ± 3.24	< 0.001
LV mass (gm)	100.37 ± 18.24	109.80 ± 19.00	0.01	104.32 ± 19.02	101.33 ± 21.00	0.59
LV mass index (gm/m^2)	63.83 ± 9.76	64.87 ± 9.25	0.60	63.49 ± 8.44	62.03 ± 10.27	0.57
LV hypertrophy	2 [4.3]	1 [2.4]	0.62	0 [0.0]	1 [3.6]	0.34
RV hypertrophy	0 [0.0]	6 [14.3]	0.007	2 [8.0]	1 [3.6]	0.48
LV ejection fraction (%), PLAX	62.15 ± 4.67	61.17 ± 4.60	0.32	63.32 ± 5.08	62.14 ± 5.34	0.41
Aortic regurgitation ≥ mild grade	0 [0.0]	1 [2.4]	0.28	1 [4.0]	0 [0.0]	0.28
Mitral regurgitation ≥ mild grade	32 [68.1]	31 [73.8]	0.55	21 [84.0]	21 [75.0]	0.42
Pulmonary regurgitation ≥ mild grade	31 [66.0]	26 [61.9]	0.69	19 [76.0]	20 [71.4]	0.70
Tricuspid regurgitation ≥ mild grade	37 [78.7]	35 [83.3]	0.58	23 [92.0]	27 [96.4]	0.48
RV systolic pressure (mmHg)	26.94 ± 5.33	27.81 ± 3.76	0.38	27.56 ± 3.58	27.96 ± 4.41	0.71
E-wave velocity (cm/sec)	91.96 ± 14.20	92.66 ± 19.51	0.84	95.48 ± 15.91	94.36 ± 15.29	0.79
A-wave velocity (cm/sec)	49.68 ± 9.12	53.27 ± 11.88	0.11	50.19 ± 10.58	48.97 ± 9.40	0.65
Mitral inflow E/A ratio	1.89 ± 0.38	1.81 ± 0.53	0.38	1.99 ± 0.59	1.99 ± 0.49	0.99
E′ velocity (cm/sec)	17.48 ± 3.55	17.99 ± 3.92	0.52	18.50 ± 4.34	19.69 ± 4.31	0.32
A′ velocity (cm/sec)	8.32 ± 2.18	9.32 ± 2.70	0.057	9.34 ± 2.31	8.67 ± 2.11	0.27
Lateral mitral annulus E′/A′ ratio	2.23 ± 0.72	2.05 ± 0.61	0.19	2.09 ± 0.74	2.41 ± 0.83	0.15

Continuous variables are expressed as mean ± SD (standard deviation), and categorical variables as N [%].

LV, left ventricle; PLAX, echocardiographic parasternal long axis view; PSAX, echocardiographic parasternal short axis view; RV, right ventricle.

Supplemental Table 6. A comparison in indexed LV and RVOT dimensions between female and male athletes

	Indexed LV dimension (mm/m^2)		Indexed RVOT dimension (mm/m^2)	
	CHIEF-Heart	D'Ascenzi et al.[#]	CHIEF-Heart	D'Ascenzi et al.[#]
Endurance Athletes				
Women	28.22 ± 2.12	29.8 ± 2.4	16.91 ± 2.46	16.4 ± 2.5
Men	27.84 ± 2.02*	28.6 ± 2.3	14.36 ± 2.31*	15.1 ± 1.9
p value	0.80	< 0.01	0.01	< 0.01
Strength Athletes				
Women	28.00 ± 2.91	29.2 ± 2.9	17.29 ± 2.58	15.0 ± 1.8
Men	27.43 ± 2.34*	26.9 ± 2.2	14.58 ± 2.15*	14.2 ± 1.7
p value	0.88	< 0.01	0.003	NS

Data were presented as mean ± standard deviation, and compared by analysis of variance between men and women.

LV, left ventricular end-diastolic dimension; RVOT, right ventricular outflow tract.

* The data for men in the CHIEF Heart Study were obtained from our prior study (reference 15).

[#] The data for the D'Ascenzi et al. study were obtained from the reference 43.