Athlete’s Heart in Asian Military Males: The CHIEF Heart Study

Pang-Yen Liu1,2†, Kun-Zhe Tsai1,3†, Joao A. C. Lima4, Carl J. Lavie5 and Gen-Min Lin1,2*

1 Department of Internal Medicine, Hualien Armed Forces General Hospital, Hualien City, Taiwan, 2 Department of Internal Medicine, Tri-Service General Hospital and National Defense Medical Center, Taipei, Taiwan, 3 Department of Dentistry, Tri-Service General Hospital and National Defense Medical Center, Taipei, Taiwan, 4 Departments of Cardiology and Radiology, Johns Hopkins University School of Medicine, Baltimore, MD, United States, 5 Ochsner Clinical School, John Ochsner Heart and Vascular Institute, The University of Queensland School of Medicine, New Orleans, LA, United States

Background: Elite athlete’s heart is characterized by a greater left ventricular mass indexed by body surface area (LVMI) and diastolic function; however previous studies are mainly conducted in non-Asian athletes compared to sedentary controls.

Methods: This study included 1,388 male adults, aged 18–34 years, enrolled in the same unified 6-month physical training program in Taiwan. During the midterm exams of 2020, all trainees completed a 3-km run (endurance) test, and 577 were randomly selected to attend a 2-min push-up (muscular strength) test. Elite athletes were defined as the performance of each exercise falling one standard deviation above the mean (16%). Cardiac structure and function were measured by echocardiography and compared between elite and non-elite athletes. Multiple logistic regression analysis was used to determine the independent predictors of elite athlete status at each exercise modality.

Results: As compared to non-elite controls, elite endurance athletes had greater LVMI (84.4 ± 13.6 vs. 80.5 ± 12.9 g/m², p < 0.001) and lateral mitral E’/A’ ratio (2.37 ± 0.73 vs. 2.22 ± 0.76, p < 0.01) with lower late diastolic A’ (7.77 ± 2.16 vs. 8.30 ± 3.69 cm/s, p = 0.03). Elite strength athletes had greater LVMI (81.8 ± 11.4 vs. 77.5 ± 12.1, p = 0.004) and lateral mitral E’/A’ ratio (2.36 ± 0.70 vs. 2.11 ± 0.71, p < 0.01) with a greater early diastolic E’ (19.30 ± 4.06 vs. 18.18 ± 4.05 cm/s, p = 0.02). Greater LVMI and lower heart rate were independent predictors of elite endurance athletes [odds ratio (OR) and 95% confidence intervals: 1.03 (1.02, 1.04) and 0.96 (0.95, 0.98), respectively]. Greater LVMI, lateral mitral E’/A’ ratio and right ventricular systolic pressure were independent predictors of elite strength athletes [OR: 1.03 (1.01, 1.05), 1.50 (1.06, 2.12), and 1.12 (1.05, 1.19), respectively].

Conclusions: Cardiac structural and functional characteristics differ between endurance and strength elite athletes. While greater LVMI predicts elite status in both groups of Asian athletes, consistent with findings from Western elite athletes, greater diastolic function, and right ventricular systolic pressure characterize strength elite athletes, while lower heart rate at rest predicts endurance elite athletic status.

Keywords: Asian athletes, cardiac remodeling, endurance exercise performance, muscular strength exercise, left ventricular diastolic function
INTRODUCTION

Aerobic and anaerobic fitness have been associated with cardiovascular (CV) health and mortality in the general population (1, 2). The performance in endurance and muscular strength exercises correlated well with aerobic and anaerobic fitness can modulate cardiac structure remodeling and diastolic left ventricular (LV) function. Prior studies have shown that elite athletes, such as Olympic athletes and US football players, had greater LV mass index (LVMI) and diastolic function measured by transthoracic echocardiography (3–5). In summary, elite athletes who expertise endurance exercise, or muscular strength exercise, or both had a greater LVMI than sedentary individuals or the reference values according to age suggested by the U.S. and European echocardio graphic societies (6). With regard to the LV diastolic function, the E/A ratio evaluated by mitral inflow Doppler Doppler imaging by sepal or lateral wall motion, the E'/A' ratio is significantly greater in athletes for an enhanced peak early E' or a reduced late atrial A' tissue velocity than controls (7–9). Moreover, prior studies compared elite athletes to sedentary controls (5–7). As the LV diastolic function is assessed by tissue Doppler imaging of sepal or lateral wall motion, the E'/A' ratio is significantly greater in athletes for an enhanced peak early E’ or a reduced late atrial A’ tissue velocity than controls (6–8). Currently, these findings for athlete's heart are mainly from the Western Countries. Previous reports have revealed racial differences in the physiologically cardiac adaptions to regular exercise and to LV pressure overload (9–11). For given levels of physical training, athletes of African/Afro-Caribbean descent display more marked cardiac structure changes than do Caucasian athletes (10, 11), possibly due in part to genetic variations. However, there have been rare studies investigating CV health in Asian athletes. Moreover, prior studies compared elite athletes to sedentary controls but rarely to those in a similar training program whether the marked cardiac adaptations in elite athletes are also observed in physically active individuals are unknown (12). Therefore the aim of this study is to investigate the cardiac structure and function of elite athletes from a military population of physically active males in Taiwan.

METHODS

Study Population

The cardiorespiratory fitness and hospitalization events in armed forces study (CHIEF Heart Study) included 1,388 military males, aged 18–34 years, from the ROC Army Huadong Defense Command Base, in Taiwan in January 2020 (13–17). All participants underwent the annual health examination, and self-reported a questionnaire for their habits of toxic substance use and history of cardiovascular (CV) health and mortality in the general population (1, 2). The performance in endurance and muscular strength exercises correlated well with aerobic and anaerobic fitness can modulate cardiac structure remodeling and diastolic left ventricular (LV) function. The overall subjects by the Commander for a 2-min push-up test only when the product of outdoor temperature (°C) and relative humidity (%) × 0.1 was <40 and the weather was not raining. The muscular strength capacity of each participant was investigated by the 2-min push-up performance (2, 19). The endurance capacity, and 577 participants randomly selected from the overall subjects by the Commander for a 2-min push-up test only when the product of outdoor temperature (°C) and relative humidity (%) × 0.1 was <40 and the weather was not raining. The muscular strength capacity of each participant was investigated by the 2-min push-up performance (2, 19). The upward and downward movements of push-ups were scored only if the examinee's back and buttock line got the baseline peak and bottom levels set by the infrared sensors of a computerized scoring system during the priming period. However, the push-up test was aborted when any parts of the examinee's body except the hands and feet touched the floor before the time ran out (2 min).

TTE Measurements

These, 1,388 participants received a 3-km run for examining their endurance capacity, and 577 participants randomly selected from the overall subjects by the Commander for a 2-min push-up test only when the product of outdoor temperature (°C) and relative humidity (%) × 0.1 was <40 and the weather was not raining. The muscular strength capacity of each participant was investigated by the 2-min push-up performance (2, 19). The upward and downward movements of push-ups were scored only if the examinee's back and buttock line got the baseline peak and bottom levels set by the infrared sensors of a computerized scoring system during the priming period. However, the push-up test was aborted when any parts of the examinee's body except the hands and feet touched the floor before the time ran out (2 min).
and the E’/A’ ratio. RV systolic pressure (RVSP) was assessed by the continuous wave Doppler in the four-chamber window.

### Statistical Analysis

Elite athletes were defined as the score of each exercise falling one standard deviation above the mean (16%), and the controls were the other physically active males not getting to the level of elite athletes in each exercise (84%). Demographic, anthropometric, ECG and TTE characteristics of the elite athletes and the non-elite controls were expressed as mean ± standard deviation for continuous variables and numbers (%) for categorical variables, respectively. Continuous variables were compared by analysis of variance (ANOVA) and categorical variables were compared by chi-square or Fisher’s exact test. Dimensions of cardiac chambers and wall thickness were compared utilizing analysis of covariance (ANCOVA) with adjustment for body surface area. Multiple logistic regressions were used to determine the odds ratio (OR) of the TTE characteristics with the elite athletes to non-elite controls. In model 1, age, smoking, LVMI, RVSP, and lateral mitral E’/A’ ratio were adjusted. In model 2, BMI was additionally adjusted. In model 3, mean BP was additionally adjusted. In model 4, heart rate was further adjusted. 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 was approved by the Institutional Review Board of the Mennonite Christian Hospital (No. 16-05-008) in Taiwan, and written informed consent was obtained from all participants.

### RESULTS

#### Clinical Features and Laboratory Findings

There were 233 males (16.8%) classified as elite endurance athletes who spent >780 s for a 3-km run and the other 1,155 physically active males (93.2%) were classified as non-elite controls (Table 1). In addition, there were 78 males (13.5%) classified as elite strength athletes who performed more than 54 push-ups within 2 min and the other 499 physically active males (86.5%) were classified as non-elite controls. Elite endurance athletes had lower levels of body weight related anthropometrics, such as BMI and waist circumference (WC), systolic BP, fasting plasma glucose and low-density lipoprotein, a higher level of high-density lipoprotein, and a relatively better 2-min push-ups score (49.9 ± 12.3 vs. 45.5 ± 10.0). Elite strength athletes had a lower WC and a higher high-density lipoprotein, and a relatively better 3-km run score (833.2 ± 82.2 vs. 869.8 ± 81.6 s).

### ECG Features

In Table 2, elite endurance athletes had significantly slower heart rate (sinus bradycardia), greater QRS duration and axis, and a higher prevalence of ECG-based LV hypertrophy (70.8 vs. 54.8%,

---

### TABLE 1 | Clinical characteristics of elite endurance and strength athletes and non-elite controls.

| Clinical characteristics | Participants attending a 3-KM run test ($N = 1,388$) | Participants attending a 2-min push-up test ($N = 577$) |
|--------------------------|------------------------------------------------------|-------------------------------------------------|
| Age (years)              | Elite endurance athletes ($≥$780 s) ($N = 233$) | Controls ($≥$780 s) ($N = 1,155$) | $P$-value |
| (Range: min–max)         | 25.04 ± 3.64                                       | 25.21 ± 3.68                                   | 0.52 |
| Height (cm)              | 171.65 ± 5.61                                      | 172.21 ± 5.76                                  | 0.17 |
| Weight (kg)              | 68.43 ± 9.23                                       | 73.58 ± 12.08                                  | <0.001 |
| Body mass index (kg/m²)  | 23.20 ± 2.75                                       | 24.77 ± 3.62                                   | <0.001 |
| Body surface area (m²)   | 1.80 ± 0.13                                        | 1.87 ± 0.16                                    | <0.001 |
| Waist circumference (cm) | 78.51 ± 6.97                                       | 83.10 ± 41                                     | <0.001 |
| Systolic blood pressure (mmHg) | 116.07 ± 11.18                           | 118.46 ± 12.30                                  | 0.006 |
| Diastolic blood pressure (mmHg) | 67.94 ± 8.41                                 | 69.15 ± 9.40                                   | 0.07 |
| Blood test               |                                                     |                                                |      |
| Creatinine (mg/dL)       | 0.94 ± 0.10                                        | 0.94 ± 0.11                                    | 0.96 |
| Total cholesterol (mg/dL)| 167.14 ± 31.83                                     | 167.68 ± 32.10                                  | 0.81 |
| HDL-C (mg/dL)            | 52.55 ± 10.69                                      | 48.40 ± 9.72                                   | <0.001 |
| LDL-C (mg/dL)            | 98.40 ± 26.46                                      | 103.20 ± 28.77                                  | 0.01 |
| Triglycerides (mg/dL)    | 86.51 ± 71.72                                      | 100.63 ± 76.39                                  | 0.009 |
| Fasting glucose (mg/dL)  | 91.36 ± 8.32                                       | 92.95 ± 10.02                                   | 0.02 |
| Current tobacco smoking  | 87 [37.3]                                          | 522 [45.2]                                     | 0.02 |
| Exercise performance     |                                                     |                                                |      |
| 3-KM running (seconds)   | 748.08 ± 31.71                                     | 880.12 ± 74.30                                  | <0.001 |
| 2-min push-ups (numbers)*| 49.95 ± 12.28                                      | 45.54 ± 10.04                                   | <0.001 |

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

HDL-C: high-density lipoprotein cholesterol; KM: kilometer; LDL-C: low-density lipoprotein cholesterol.

* $N = 577$. 

---
TABLE 2 | Electrocardiographic characteristics of elite endurance and strength athletes and non-elite controls.

| ECG characteristics | Participants attending a 3-KM run test (N = 1,388) | Participants attending a 2-min push-up test (N = 577) |
|---------------------|----------------------------------------------------|--------------------------------------------------|
|                     | Elite endurance athletes (≥780 s) (N = 233)        | Controls (≥780 s) (N = 1,155)  | P-value | Elite strength athletes (≥54 times) (N = 78) | Controls (≤54 times) (N = 499) | P-value |
| Heart rate (beats/min) | 61.93 ± 10.02                                      | 66.68 ± 10.58                          | <0.001  | 65.37 ± 12.05                                   | 66.03 ± 10.62                           | 0.61   |
| P duration (ms)      | 106.36 ± 11.78                                     | 105.90 ± 14.05                         | 0.64    | 108.35 ± 11.75                                   | 105.56 ± 14.57                         | 0.10   |
| PR interval (ms)     | 156.77 ± 16.56                                     | 155.62 ± 18.81                         | 0.38    | 156.41 ± 16.78                                   | 154.71 ± 19.93                         | 0.47   |
| QRS duration (ms)    | 99.95 ± 11.23                                      | 97.90 ± 10.95                          | 0.03    | 98.62 ± 10.21                                    | 97.25 ± 10.02                          | 0.26   |
| QTc interval (ms)    | 387.02 ± 21.95                                     | 388.67 ± 22.81                         | 0.30    | 392.23 ± 26.56                                   | 387.75 ± 21.73                         | 0.10   |
| QRS axis (degree)    | 71.06 ± 22.00                                      | 62.89 ± 31.61                          | <0.001  | 64.69 ± 25.05                                    | 65.00 ± 28.22                          | 0.92   |
| ECG based LVH (%)    | 165 [70.8]                                         | 633 [54.8]                             | <0.001  | 51 [65.4]                                        | 290 [58.7]                             | 0.26   |
| ECG based RVH (%)    | 35 [15.1]                                          | 177 [15.3]                             | 0.92    | 13 [16.7]                                        | 81 [16.2]                              | 0.92   |
| Sinus bradycardia (%)| 102 [43.8]                                         | 295 [25.5]                             | <0.001  | 28 [35.9]                                        | 137 [21.5]                             | 0.12   |
| Ectopic P rhythm (%) | 19 [8.2]                                           | 108 [9.4]                              | 0.56    | 5 [6.4]                                          | 55 [11.0]                              | 0.21   |
| Left atrial enlargement (%) | 36 [15.5]                                          | 190 [17.2]                             | 0.50    | 11 [14.1]                                        | 81 [16.2]                              | 0.63   |
| First degree atrioventricular block (%) | 3 [1.3]                                          | 25 [2.2]                              | 0.38    | 2 [2.8]                                          | 9 [1.8]                                | 0.64   |
| Left axis deviation (%) | 0 [0.0]                                          | 18 [1.6]                              | 0.05    | 2 [2.8]                                          | 3 [0.6]                                | 0.08   |
| Right axis deviation (%) | 30 [12.9]                                          | 123 [10.6]                             | 0.32    | 5 [6.4]                                          | 50 [10.0]                              | 0.31   |
| Complete right bundle branch block (%) | 12 [5.1]                                          | 42 [3.6]                              | 0.27    | 2 [2.8]                                          | 14 [2.8]                               | 0.90   |
| Incomplete right bundle branch block (%) | 23 [9.9]                                          | 79 [6.8]                              | 0.10    | 8 [10.3]                                         | 30 [6.0]                               | 0.16   |
| QTc prolongation > 480 ms (%) | 1 [0.4]                                          | 7 [0.6]                              | 0.74    | 2 [2.8]                                          | 2 [0.4]                                | 0.03   |
| T wave inversion (%) | 6 [2.6]                                           | 37 [3.2]                              | 0.61    | 2 [2.8]                                          | 15 [3.0]                               | 0.83   |

Categorical variables are expressed as N [%].
ECG, electrocardiography; LVH, left ventricular hypertrophy; KM, kilometer; RVH, right ventricular hypertrophy.

p < 0.001) according to the Soklow-Lyon voltage criterion (23). Elite strength athletes merely had a higher prevalence of the corrected QT interval prolongation >480 ms on the basis of the Bazett's formula (2.6 vs. 0.4%, p = 0.03) (24).

TTE Findings
In Table 3, elite athletes and non-elite controls had similar chamber dimensions of left atrium, LV and RV in diastole, and similar LVM and RV wall thickness, except that elite endurance athletes had greater LV diastolic dimension with adjustment for body surface area. As compared to non-elite controls, elite endurance athletes had greater LVMI (84.4 ± 13.6 vs. 80.5 ± 12.9 g/m², p < 0.001) and lateral mitral annulus E’/A’ ratio (2.37 ± 0.73 vs. 2.22 ± 0.76, p < 0.01) with lower late diastolic A’ (7.77 ± 2.16 vs. 8.30 ± 3.69 cm/s, p = 0.03). In contrast, elite strength athletes had greater LVMI (81.8 ± 11.4 vs. 77.5 ± 12.1 g/m², p = 0.004), lateral mitral E’/A’ ratio (2.36 ± 0.70 vs. 2.11 ± 0.71, p < 0.01) with greater early diastolic E’ (19.30 ± 4.06 vs. 18.18 ± 4.05 cm/s, p = 0.02) and RVSP (29.60 ± 4.35 vs. 27.83 ± 3.71 mmHg, p < 0.001).

Echocardiographic Predictors of Elite Athletes
Table 4 demonstrates the results of multiple logistic regression analysis for the predictors of elite endurance and strength athletes, respectively. In model 1, greater LVMI and lateral mitral E’/A’ were independent predictors of elite endurance athletes. However, the association for the lateral mitral E’/A’ ratio was null after additionally controlling for BMI. In model 4, Greater LVMI, and lower heart rate and BMI were independent predictors of elite endurance athletes [odds ratio (OR): 1.03 (95% confidence intervals (CI): 1.02, 1.04), 0.96 (95% CI: 0.95, 0.98) and 0.85 (95% CI: 0.81, 0.90), respectively]. In contrast, greater LVMI, lateral mitral E’/A’ and RVSP were independent predictors of elite strength athletes [OR: 1.03 (95% CI: 1.01, 1.05), 1.50 (95% CI: 1.06, 2.12) and 1.12 (95% CI: 1.05, 1.19), respectively] in model 4. Both BMI and heart rate were not independent predictors of elite strength athletes.

DISCUSSION
This study is the largest report to date to demonstrate the cardiac structure and function in Asian male athletes and compare them to physically active controls and to determine the predictors or elitelessness based on endurance and muscular strength. The main findings in the present study were that elite endurance male athletes had greater LVMI and LV diastolic function which might be due to reduced heart rate. Greater LVMI, and lower heart rate and BMI were the independent predictors of falling in the elite endurance category. Elite strength male athletes also had greater LVMI and LV diastolic function; greater LVMI, lateral mitral E’/A’ and RVSP were the independent predictors of being in the elite strength category.

Both elite endurance and strength athletes had greater LVMI, and endurance athletes had greater LV chamber size, which were consistent with the findings in prior studies (6, 25).
Mechanisms for the LV hypertrophy induced by exercises have been proposed by a physiological compensation of cardiac muscle cells elongation in response to chronic hemodynamic overload that is regulated in part by the renin-angiotensin system (26, 27). The greater LV chamber size related to endurance exercises has been explained mainly by volume overload, but the LV chamber size is not enlarged in response to strength exercises (28). Although the LVMI of elite Asian male athletes in the present study was generally smaller than that reported in prior studies for Black and White male athletes, possibly due to the ethnic or racial differences in the genetic aspect, this study further confirmed the concept that LVMI could independently predict the performance of endurance and strength exercises in physically active males.

With regard to the enhanced LV diastolic function, the present study for elite Asian male athletes showed consistent results that elite endurance athletes had slightly greater E/A ratio due to a decrease in peak A wave velocity, and elite strength athletes had similar E/A ratio compared to their non-elite controls (11). In addition, with regard to the tissue Doppler image results, the greater lateral mitral E’/A’ ratio in elite endurance athletes were due to a reduced A’ velocity, whereas the greater lateral mitral E’/A’ ratio in elite strength athletes were due to an increased peak E’ velocity (6–8). In the multiple logistic regression model, the enhanced LV diastolic function in elite endurance athletes was due to a reduced resting heart rate, (29) and that in elite strength athletes might be related to an improved LV compliance. The reduced heart rate related to endurance exercise has been associated with an increase of parasympathetic tone (30). On the contrary, physically active Asian males regardless of endurance or strength exercise in the present study had a similar RVSP (25–29 mmHg) compared to non-Asian endurance athletes (26–27 mmHg), which was higher than that in sedentary controls in prior studies (16–22 mmHg) (25, 31). D’Andrea et al. reported that the RVSP was associated with RV chamber size and was higher in endurance athletes than strength athletes (20 mmHg) (25). However, the findings for right heart structure and function were contrary to the present study results whether these conflicts

### TABLE 3 | Echocardiographic characteristics of elite endurance and strength athletes and non-elite controls.

| Echocardiographic characteristics | Participants attending a 3-KM run test (N = 1,388) | Participants attending a 2-min push-up test (N = 577) |
|----------------------------------|------------------------------------------|------------------------------------------|
|                                  | Elite endurance athletes (≥780 s) (N = 233) | Controls (<780 s) (N = 1,155) | P-value |
|                                  | Elite strength athletes (≥54 times) (N = 78) | Controls (<54 times) (N = 499) | P-value |
| Aortic valve open (mm), PLAX     | 19.93 ± 1.98                              | 20.03 ± 1.91                          | 0.57* |
|                                  |                                          |                                          |       |
| Aortic root dimension (mm), PALX | 29.49 ± 3.23                              | 29.68 ± 3.25                          | 0.66* |
|                                  |                                          |                                          |       |
| LV posterior wall (mm), PLAX     | 8.44 ± 0.89                               | 8.54 ± 0.94                           | 0.31* |
|                                  |                                          |                                          |       |
| LV internal dimension in diastole (mm), PLAX | 50.03 ± 3.35 | 49.24 ± 3.42                           | 0.003* |
|                                  |                                          |                                          |       |
| Interventricular septum, (mm), PLAX | 8.61 ± 0.95 | 8.74 ± 1.02                            | 0.44* |
|                                  |                                          |                                          |       |
| RV wall thickness (mm), PLAX*    | 4.72 ± 0.55                               | 4.66 ± 0.62                           | 0.98* |
|                                  |                                          |                                          |       |
| RV outflow tract dimension in diastole (mm), PLAX | 25.94 ± 3.84 | 27.19 ± 12.49                          | 0.82* |
|                                  |                                          |                                          |       |
| Left atrial dimension (mm), PLAX | 32.55 ± 4.00                              | 32.96 ± 3.93                          | 0.21* |
|                                  |                                          |                                          |       |
| LV mass index (gm/m²)           | 152.53 ± 28.43                            | 151.05 ± 29.83                        | 0.16  |
|                                  |                                          |                                          |       |
| LV mass (gm)                    | 84.44 ± 13.56                             | 80.52 ± 12.94                         | <0.001|
|                                  |                                          |                                          |       |
| LV hypertrophy                  | 11 [4.7]                                 | 24 [2.1]                              | 0.01  |
|                                  |                                          |                                          |       |
| RV hypertrophy                  | 20 [8.6]                                 | 84 [7.3]                              | 0.48  |
|                                  |                                          |                                          |       |
| LV ejection fraction (%)        | 61.79 ± 5.03                              | 61.97 ± 5.06                          | 0.78  |
|                                  |                                          |                                          |       |
| Tricuspid valve prolapse, PSAX  | 34 [20.4]                                | 206 [26.6]                            | 0.09  |
|                                  |                                          |                                          |       |
| Aortic regurgitation ≥ mild grade | 3 [1.3]                                 | 13 [1.1]                              | 0.83  |
|                                  |                                          |                                          |       |
| Mitral regurgitation ≥ mild grade | 190 [81.5]                              | 890 [77.1]                            | 0.13  |
|                                  |                                          |                                          |       |
| Pulmonary regurgitation ≥ mild grade | 162 [69.5]                              | 763 [66.1]                            | 0.30  |
|                                  |                                          |                                          |       |
| Tricuspid regurgitation ≥ mild grade | 196 [84.1]                             | 928 [80.3]                            | 0.08  |
|                                  |                                          |                                          |       |
| RV systolic pressure (mmHg)     | 27.68 ± 4.35                              | 27.19 ± 4.36                          | 0.27  |
|                                  |                                          |                                          |       |
| Mitral inflow power Doppler E-wave (m/s) | 87.00 ± 14.13                         | 86.21 ± 14.87                         | 0.45  |
|                                  |                                          |                                          |       |
| Mitral inflow power Doppler A-wave (m/s) | 46.44 ± 9.59                           | 48.69 ± 9.81                          | 0.001 |
|                                  |                                          |                                          |       |
| E/A ratio                        | 1.94 ± 0.46                               | 1.83 ± 0.46                           | 0.001 |
|                                  |                                          |                                          |       |
| Mitral lateral annulus tissue Doppler E’ (cm/s) | 17.33 ± 3.83                           | 17.04 ± 3.75                          | 0.29  |
|                                  |                                          |                                          |       |
| Mitral lateral annulus tissue Doppler A’ (cm/s) | 7.77 ± 2.16                            | 8.30 ± 3.69                           | 0.03  |
|                                  |                                          |                                          |       |
| E’/A’ ratio                      | 2.37 ± 0.73                               | 2.22 ± 0.76                           | 0.007 |

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.
*Analysis of covariance (ANCOVA) with adjustment for body surface area.
were because of racial/ethnic differences or for a presence of confounders such as the smoking habit which was not considered in prior studies requires further investigation.

### Study Strengths and Limitations

The major strength of the present study was that the male participants were enrolled in the same army camp in Taiwan where the training program was standardized. In addition, since the army base is a closed system, the living environment for the participants is very similar and their daily schedule, such as the wake up time, bed time, meal time and the frequency of sentry duty is unified. Third, the detailed information for the baseline confounders such as the smoking habit which was not considered in prior studies requires further investigation.

### CONCLUSION

Our study uncovered that cardiac structural and functional characteristics differ between endurance and strength elite athletes in a physically active Asian male population. While greater LVMI predicts elite status in both groups of Asian athletes, consistent with findings from Western elite athletes, greater diastolic function and RV systolic pressure characterize strength elite athletes, while lower heart rate at rest predicts endurance elite athletic status.

### DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

### ETHICS STATEMENT

This study was approved by the Institutional Review Board of the Mennonite Christian Hospital (No. 16-05-008) in Taiwan, and

---

**TABLE 4** | Multivariable logistic regression analysis for elite endurance and strength athletes.

| Characteristics | Model 1 | | | Model 2 | | | Model 3 | | | Model 4 | | |
|-----------------|---------|------------|-----------------|---------|------------|-----------------|---------|------------|-----------------|---------|------------|-----------------|---------|
|                 | OR      | 95% CI     | P-value         | OR      | 95% CI     | P-value         | OR      | 95% CI     | P-value         | OR      | 95% CI     | P-value         |
| Elite endurance athletes (N = 1,388) |         |            |                 |         |            |                 |         |            |                 |         |            |                 |
| Age             | 0.998   | 0.959–1.039| 0.93            | 1.025   | 0.983–1.068| 0.24            | 1.028   | 0.986–1.071| 0.19            | 1.021   | 0.979–1.065| 0.32            |
| Tobacco smoking | 0.704   | 0.525–0.943| 0.01            | 0.694   | 0.515–0.936| 0.01            | 0.687   | 0.509–0.927| 0.01            | 0.759   | 0.560–1.029| 0.07            |
| LV mass index   | 1.023   | 1.012–1.034| <0.001          | 1.031   | 1.020–1.043| <0.001          | 1.032   | 1.021–1.044| <0.001          | 1.027   | 1.015–1.039| <0.001          |
| RV systolic pressure | 1.027 | 0.994–1.061| 0.11            | 1.018   | 0.985–1.063| 0.28            | 1.018   | 0.984–1.053| 0.30            | 1.019   | 0.985–1.054| 0.28            |
| E'/A' ratio     | 1.291   | 1.072–1.566| 0.007           | 1.163   | 0.958–1.411| 0.12            | 1.159   | 0.965–1.407| 0.13            | 1.078   | 0.883–1.312| 0.48            |
| Body mass index |        |            |                 |         |            |                 |         |            |                 |         |            |                 |
| Mean blood pressure |     |            |                 |         |            |                 |         |            |                 |         |            |                 |
| Heart rate      |        |            |                 |         |            |                 |         |            |                 |         |            |                 |

Elite strength athletes (N = 577)

| Characteristics | Model 1 | | | Model 2 | | | Model 3 | | | Model 4 | | |
|-----------------|---------|------------|-----------------|---------|------------|-----------------|---------|------------|-----------------|---------|------------|-----------------|---------|
| Age             | 1.013   | 0.947–1.085| 0.70            | 1.023   | 0.954–1.096| 0.52            | 1.028   | 0.958–1.103| 0.44            | 1.030   | 0.960–1.106| 0.40            |
| Tobacco smoking | 1.171   | 0.714–1.918| 0.53            | 1.191   | 0.726–1.954| 0.49            | 1.189   | 0.724–1.954| 0.49            | 1.170   | 0.710–1.928| 0.53            |
| LV mass index   | 1.027   | 1.007–1.048| 0.008           | 1.029   | 1.008–1.050| 0.006           | 1.030   | 1.009–1.051| 0.005           | 1.031   | 1.010–1.053| 0.004           |
| RV systolic pressure | 1.124 | 1.056–1.197| <0.001          | 1.122   | 1.053–1.195| <0.001          | 1.121   | 1.052–1.195| <0.001          | 1.121   | 1.052–1.194| <0.001          |
| E'/A' ratio     | 1.540   | 1.108–2.141| 0.01            | 1.480   | 1.058–2.072| 0.02            | 1.470   | 1.050–2.056| 0.02            | 1.500   | 1.063–2.116| 0.02            |
| Body mass index |        |            |                 |         |            |                 |         |            |                 |         |            |                 |
| Mean blood pressure |     |            |                 |         |            |                 |         |            |                 |         |            |                 |
| Heart rate      |        |            |                 |         |            |                 |         |            |                 |         |            |                 |

Data are presented as odds ratios (OR) and 95% CI (confidence intervals) using multiple logistic regression. LV, left ventricle; RV, right ventricle. Model 1 covariates included age, tobacco smoking and left ventricular mass index; Model 2 covariates included Model 1 covariates plus body mass index; Model 3 covariates included Model 2 covariates plus mean blood pressure; Model 4 covariates included Model 3 covariates plus heart rate.
written informed consent was obtained from all participants. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

P-YL and G-ML wrote the paper. K-ZT made the statistical analyses. JL and CL released critical comments for the paper and edited the manuscript. G-ML was the principal investigator for the study. All authors contributed to the article and approved the submitted version.

REFERENCES

1. Kodama S, Saito K, Tanaka S, Maki M, Yachi Y, Asumi M, et al. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. JAMA. (2009) 301:2024–35. doi: 10.1001/jama.2009.681
2. Yang J, Christophi CA, Farioli A, Baur DM, Moffatt S, Zollinger TW, et al. Association between push-up exercise capacity and future cardiovascular events among active adult men. JAMA Netw Open. (2019) 2:e188341. doi: 10.1001/jamanetworkopen.2018.8341
3. Casselli S, Di Paolo FM, Piscicchio C, Pandian NG, Pelliccia A. Patterns of left ventricular diastolic function in Olympic athletes. J Am Soc Echocardiogr. (2015) 28:236–44. doi: 10.1016/j.echo.2014.09.013
4. Kim JH, Hollowed C, Liu C, Al-Badri A, Alkhorde A, Dommis M, et al. Hypertension, and the emergence of a maladaptive cardiovascular phenotype among US football players. JAMA Cardiol. (2019) 4:1221–9. doi: 10.1001/jamacardio.2019.3909
5. Cohan SD, Sanders SP, MacPherson D, Borow KM. Left ventricular diastolic function in elite athletes with physiologic cardiac hypertrophy. J Am Coll Cardiol. (1985) 6:545–9. doi: 10.1016/S0735-1097(85)80111-X
6. Pluim BM, Zwindermer AH, van der Laarse A, van der Wall EE. The athlete’s heart. a meta-analysis of cardiac structure and function. Circulation. (2000) 101:336–44. doi: 10.1161/01.CIR.101.3.336
7. George KP, Samauroj J. Left ventricular diastolic function in athletes. Dtsch Z Sportmed. (2012) 63:63–8. doi: 10.5960/dszm.2012.008
8. Baldi JC, McFarlane K, Oxenham HC, Whalley GA, Walsh HJ, Doughty RN. Left ventricular diastolic filling and systolic function of young and older trained and untrained men. J Appl Physiol. (2003) 95:2570–5. doi: 10.1152/japplphysiol.00441.2003
9. Rawlins J, Carre F, Kervio G, Papadakis M, Chandra N, Edwards C, et al. Ethnic differences in physiological cardiac adaptation to intense physical exercise in highly trained female athletes. Circulation. (2010) 121:1078–85. doi: 10.1161/CIRCULATIONAHA.109.917211
10. Papadakis M, Wilson MG, Ghani S, Kervio G, Carre F, Sharma S. Impact of ethnicity upon cardiovascular adaptation in competitive athletes: relevance to preparticipation screening. Br J Sports Med. (2012) 46(Suppl.1):i22–8. doi: 10.1136/bjsports-2012-091127
11. Sheikh N, Sharma S. Impact of ethnicity on cardiac adaptation to exercise. Nat Rev Cardiol. (2014) 11:198–217. doi: 10.1038/nrcardio.2014.15
12. Brown B, Millar L, Samauroj J, George K, Sharma S, La Gerche A, et al. Left ventricular remodeling in elite and sub-elite road cyclists. Scand J Med Sci Sports. (2020) 30:1132–9. doi: 10.1111/smss.13656
13. Chao WH, Su FY, Lin F, Yu YS, Lin GM. Association of electrocardiographic left and right ventricular hypertrophy with physical fitness of military male cadets: the CHIEF study. Eur J Sport Sci. (2019) 19:1214–20. doi: 10.1080/17461391.2019.1595741
14. Tsai KZ, Lai SW, Hsieh CJ, Lin CS, Lin YP, Tsai SC, et al. Association between mild aemia and physical fitness in a military male cohort: the CHIEF study. Sci Rep. (2019) 9:11165. doi: 10.1038/s41598-019-47625-3
15. Lin GM, Li YH, Lee CJ, Shiang JC, Lin KH, Chen KW, et al. Rationale and design of the cardiorespiratory fitness and hospitalization events in armed forces study in Eastern Taiwan. World J Cardiol. (2016) 8:646–71. doi: 10.4330/wjc.v8.i8.464
16. Lin GM, Liu K. An electrocardiographic system with anthropometrics via machine learning to screen left ventricular hypertrophy among young adults. IEEE Trans Eng Med Health. (2020) 8:1800111. doi: 10.1109/TEEMH.2020.2990073
17. 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 Trans Eng Med Health. (2020) 8:1900510. doi: 10.1109/TEEMH.2020.2996370
18. Du Bois D, Du Bois EF. A formula to estimate the approximate surface area if height and weight be known. Arch Intern Med. (1916) 17:863–871. doi: 10.1001/archinte.1916.000810300100002
19. Spurway NC. Aerobic exercise, anaerobic exercise and the lactate threshold. Br Med Bull. (1992) 48:569–91. doi: 10.1093/oxfordjournals.bmb.a072564
20. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, 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. doi: 10.1016/j.echo.2014.10.003
21. Fernandes T, Hashimoto NY, Magalhães FC, Fernandes FB, Casarini DE, Carmona AK, 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. doi: 10.1161/HYPERTENSIONAHA.110.168252
22. Su FY, Li YH, Lin YP, Lee CJ, Wang CH, Meng FC, et al. A comparison of Cornell and Sokolow-Lyon electrocardiographic criteria for left ventricular hypertrophy in a military male population in Taiwan: the Cardiorespiratory fitness and Hospitalization Events in armed Forces study. Cardiovasc Diagn Ther. (2017) 7:244–51. doi: 10.21037/cdt.2017.01.16
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. doi: 10.1016/0003-4819(49)90562-1
24. Bazett HC. An analysis of the time-relations of the electrocardiograms. Ann Noninvasive Electrocardiol. (1997) 2:177–94. doi: 10.1111/j.1542-474X.1997.tb00325.x
25. D’Andrea A, Riegler L, Morra S, Scarafile R, Salerno G, Cocchia R, et al. Two-dimensional echocardiographic study. Right ventricular morphology and function in top-level athletes: a three-dimensional echocardiographic study. J Am Soc Echocardiogr. (2012) 25:1268–76. doi: 10.1016/j.echo.2012.07.020
26. Dostal DE. The cardiac renin-angiotensin system: novel signaling mechanisms related to cardiac growth and function. Regul Pept. (2000) 91:1–11. doi: 10.1016/S0167-0115(99)00123-8
27. Morganroth J, Maron BJ, Henry WL, Epstein SE. Comparative left ventricular dimensions in trained athletes. Ann Intern Med. (1975) 82:521–4. doi: 10.7326/0002-8319-82-4-521
28. Notomi Y, Martin-Miklovic MG, Oryszak SJ, Shiota T, Deserranno D, Popovic ZB, et al. Enhanced ventricular untwisting during exercise: a mechanistic manifestation of elastic recoil described by Doppler tissue imaging.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcvm.2021.725852/full#supplementary-material
Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Copyright © 2021 Liu, Tsai, Lima, Lavie and Lin. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.