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European Heart Journal - Cardiovascular Imaging

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--Manuscript Draft--

Manuscript Number:	EHJCI-D-20-01962R4
Full Title:	The Acute Effects of an Ultramarathon on Biventricular Function and Ventricular Arrhythmias in Master Athletes
Article Type:	Original Paper
Keywords:	endurance; right ventricle; athlete's heart; master athletes; arrhythmias; speckle-tracking echocardiography; sports
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Abstract:	Background. Endurance sports practice has significantly increased over the last decades, with a growing proportion of participants older than 40 years. Although the benefits of moderate regular exercise are well known, concerns exist regarding the potential negative effects induced by extreme endurance sport. The aim of this study was to analyze the acute effects of an ultramarathon race on the ECG, biventricular function and ventricular arrhythmias in a population of master athletes. Methods. Master athletes participating in an ultramarathon (50 km, 600 meters of elevation gain) with no history of heart disease were recruited. A single-lead ECG was recorded continuously from the day before to the end of the race. Echocardiography and 12-lead resting ECG were performed before and at the end of the race. Results. The study sample consisted of 68 healthy non-professional master athletes. Compared with baseline, R-wave amplitude in V1 and QTc duration were higher after the race

	(p<0.001). Exercise-induced isolated premature ventricular beats were observed in 7% of athletes; none showed non-sustained ventricular tachycardia before or during the race. Left ventricular ejection fraction, global longitudinal strain (GLS) and twisting did not significantly differ before and after the race. After the race, no significant differences were found in right ventricular inflow and outflow tract dimensions, fractional area change, s' and GLS. Conclusions. In master endurance athletes running an ultra-marathon, exercise-induced ventricular dysfunction or relevant ventricular arrhythmias were not detected. These results did not confirm the hypothesis of a detrimental acute effect of strenuous exercise on the heart.

The Acute Effects of an Ultramarathon on Biventricular Function and Ventricular Arrhythmias in Master Athletes

Running title: Ultramarathon, ventricular function and arrhythmias

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ABSTRACT

Background. Endurance sports practice has significantly increased over the last decades, with a growing proportion of participants older than 40 years. Although the benefits of moderate regular exercise are well known, concerns exist regarding the potential negative effects induced by extreme endurance sport. The aim of this study was to analyze the acute effects of an ultramarathon race on the ECG, biventricular function and ventricular arrhythmias in a population of master athletes. **Methods.** Master athletes participating in an ultramarathon (50 km, 600 meters of elevation gain) with no history of heart disease were recruited. A single-lead ECG was recorded continuously from the day before to the end of the race. Echocardiography and 12-lead resting ECG were performed before and at the end of the race. **Results.** The study sample consisted of 68 healthy non-professional master athletes. Compared with baseline, R-wave amplitude in V1 and QTc duration were higher after the race ($p<0.001$). Exercise-induced isolated premature ventricular beats were observed in 7% of athletes; none showed non-sustained ventricular tachycardia before or during the race. Left ventricular ejection fraction, global longitudinal strain (GLS) and twisting did not significantly differ before and after the race. After the race, no significant differences were found in right ventricular inflow and outflow tract dimensions, fractional area change, s' and free wall GLS. **Conclusions.** In master endurance athletes running an ultra-marathon, exercise-induced ventricular dysfunction or relevant ventricular arrhythmias were not detected. These results did not confirm the hypothesis of a detrimental acute effect of strenuous exercise on the heart.

Keywords: endurance; right ventricle; athlete's heart; master athletes; arrhythmias; speckle-tracking echocardiography; sports

INTRODUCTION

Moderate exercise has well-recognized favorable effects on the cardiovascular system but there is an incomplete understanding of the entire dose-response relationship (1-3). Similarly to a drug, an insufficient dose may not confer the optimal benefits while an excessive dose may cause harm (4). Endurance events, including ultramarathons and long-distance races, have gained increasing popularity in recent years. Endurance athletes often exercise 15–20 times more than recommended by current guidelines (i.e. at least 75 min of vigorous-to-intensive exercise per week) (5, 6). The growing popularity of endurance and ultraendurance sport events has been paralleled by an increasing number of participants ≥40 year-old (so-called "master athletes"), that may be more prone to cumulative cardiac damage (7, 8).

Previous studies found that high-intensity exercise sessions can cause transient rise in cardiac biomarkers such as troponin and brain natriuretic peptide (BNP) and ventricular dysfunction(9, 10). Although these modifications are reversible, it has been postulated that permanent cardiac damage may develop after years of intense physical exercise (4, 11). However, few data are available on the effects of intense exercise in master athletes and previous studies investigated either electrical (by ECG and ambulatory monitoring) or structural (by echocardiography or cardiac magnetic resonance -CMR-) changes after a race.

The aim of this study was to evaluate the acute effects of an ultramarathon race on biventricular function by standard and advanced echocardiography and to assess the occurrence of ECG modifications and ventricular arrhythmias before, during and after the race in a sample of non-professional master athletes.

METHODS

The study was conducted during the 2020 "Terre di Siena Ultramarathon" (Siena, Italy) that started in San Gimignano and finished in Siena (50 km, 600 meters of elevation gain). The ultramarathon is defined as a race with distance greater than the official marathon (42,195 meters) and may vary according to certain range or time limit (i.e. 50km, 100km and longer events or 6hr, 24hr, and multi-day events) (12) (see also https://www.worldathletics.org/disciplines/ultra-running/ultra-running, last access 8th October 2020). Athletes were recruited on a voluntary basis and signed an informed consent. The study protocol was reviewed and approved by the local Ethics Committee.

Study group

Non-professional athletes ≥40-year-old participating in the "Terre di Siena Ultramarathon" were offered participation. According to Italian law, all athletes must undergo annual pre-participation evaluation (including resting and exercise ECG) to be considered eligible for sports competition. Athletes who withdrew before the finish line, arrived over the maximum time or refused to repeat the investigations after the race were excluded. A total of 71 athletes were initially enrolled: 2 of them were excluded for withdrawing before the finish line and 1 for arrival at the finish line over the maximum time. The final population consisted of 68 healthy non-professional master athletes. Demographic parameters were collected before the race (see Table 1).

Electrocardiography

All participants underwent a 12-lead resting ECG, recorded at a speed of 25 mm/s and standardized calibration for 10 mm/cm. Recordings were performed using CARDIOLINE 200S 12-lead ECGs (Cardioline S.P.A.) the day before the marathon and immediately after the race, at the finish line.

ECG tracings were reviewed independently by two experienced cardiologists (A.Z. and F.D.) and discrepancies were solved by consensus. Resting heart rate, PR interval, QRS duration, QRS axis, Sokolow-Lyon voltage, Right ventricular (RV) hypertrophy, R-wave amplitude in lead V_5-V_6, S wave amplitude in lead V_1 T-wave inversion (TWI), ST- segment depression, early repolarization were evaluated in accordance with the international criteria (13); QT interval was calculated and corrected according to the Bazett formula (13) (see Supplementary material for details).

ECG monitoring.

A single-lead ECG monitoring of 24-30 hours was performed in all athletes using the RootiRx® device (Rooti Labs Ltd., Taipei, Taiwan). RootiRx® is a small device consisting of an integrated multisensor system, a microelectronic board with memory storage and an internal rechargeable battery. It has a Conformité Européenne (CE) mark and Food and Drug Administration (FDA) clearance. After preparation of the skin, RootiRx® device was applied horizontally over the left upper pectoral region of the subject's chest using two ECG electrodes. All subjects were instructed about the device usage and their daily activities. Recordings were started the day before the race and interrupted after the end of the ultramarathon. They were reviewed independently by two experienced cardiologists (A.Z. and F.D.) and discrepancies were solved by consensus. Every single ectopic beat, pause or artefact and all families of normal beats were confirmed manually. Furthermore, the entire recording during the race was reviewed manually. The recordings were analyzed and reported separately for data obtained at rest and during the competition. Athletes with >50% of the recording time during the race not suitable for interpretation because of artifacts were excluded from the analysis.

Echocardiography

Echocardiographic examination was performed using two high-quality portable echocardiographs (Vivid iq, GE, Milwaukee, Wisconsin), equipped with an M4S 1.5-MHz to 4.0 MHz transducer, and a one-lead ECG was continuously displayed. Subjects were studied in the steep left-lateral decubitus position. Off-line data analysis was performed by two experienced readers (A. G. and F. V.) using a dedicated software (EchoPac, GE, USA). Left ventricular (LV) dimensions and LV mass were obtained as recommended (14). LV volume measurements were calculated from the apical four- and two chamber views using the modified Simpson's rule and ejection fraction (EF) was calculated (14). These measures were indexed to body surface area. RV size, outflow tract diameters and function were assessed according to the guidelines (15). RV end-diastolic and end-systolic areas were calculated by tracing the endocardium from a modified apical 4-chamber view, and RV fractional area change (RVFAC) was obtained and expressed as percentage (14). Doppler interrogation of tricuspid regurgitant jet was used to estimate pulmonary artery systolic pressure.

Pulsed-wave and tissue Doppler imaging. Pulsed-wave Doppler and tissue Doppler imaging (TDI) evaluation were recorded in the apical four-chamber view by placing the sample volume at the mitral annulus and at the septal and lateral corners of the mitral annulus respectively and the following measurements were considered E peak and A peak velocities, E/A ratio, E/e' ratio (16). TDI was also performed for the RV and s', e', and a' velocities were obtained.

Two-dimensional speckle-tracking echocardiography. 2D STE analysis was performed on narrow-sector grayscale images of LV and RV from apical and parasternal short-axis views with temporal resolution of 60–90 frames/sec. All images were optimized with gain, compression, and dynamic range to enhance myocardial definition with standardized depth, frequency, and insonation angle for all participants (17, 18). All data of speckle tracking were analysed off-line by two experienced readers (A.G. and F.V.) using

a dedicated automated software (EchoPAC PC, Version 112; GE Health Care, Milwaukee, WI). Speckle-tracking analysis of the LV and the RV has been previously described in details (17, 19, 20). Briefly, LV global longitudinal strain (GLS) was measured as the average of the LV longitudinal strain peaks obtained from 2-, 3- and 4- chamber views and LV time-to-peak (TTP) was also calculated. LV twisting curve was calculated as the net difference between peak systolic apical and basal rotation (19). RV GLS, including the interventricular septum, and RV free wall peak systolic longitudinal strain was measured as the average of the three segments (basal, mid-cavity, apical) of the lateral wall (17). Data were also reported separately for each segment and RV TTP was also obtained.

Statistical analysis

Normal distribution of all continuous variables was examined using the Shapiro-Wilk test and data are presented as mean±SD. Categorical variables are expressed as percentages. The paired t-test and the Wilcoxon matched-paired test was used to assess the within group (pre-race vs. post-race significance), according to data distribution. The McNemar test was used for nominal data. A p value <0.05 was considered statistically significant. Statistics were performed using SPSS, version 21.0 (Statistical Package for the Social Sciences Inc, Chicago, Illinois, USA).

RESULTS

The demographic characteristics of the study population are reported in Table 1. All 68 participants (mean age 47.9±7.8 years) completed the ultramarathon covering a distance of 50 km (average race time: 5.5 hours). At resting ECG before the race, TWI was found in 4 (5.8%) athletes: according to the International electrocardiographic criteria, one of these ECG patterns was diagnosed as early repolarization and the remaining three were considered pathological (TWI antero-lateral, inferior, and lateral, respectively). Nevertheless, the echocardiography and cardiac magnetic resonance subsequentially performed in these subjects excluded any structural heart disease. The comparison between pre-race and post-race ECG data is reported in Table 2. Compared with baseline, R-wave amplitude in V1 was higher after the race ($p<0.001$). QT interval significantly differed, with a shorter QT duration and a longer QTc duration found after the race compared with baseline ($p<0.001$ for both). No significant differences were found in terms of early repolarization, ST-segment depression, LV and RV hypertrophy, and QRS duration. Premature atrial or ventricular beats were not recorded in any 12-lead resting ECG.

Holter ECG monitoring before and during the race

Of 68 athletes, 9 were excluded from the analysis because of artifacts that prevented interpretation of the ECG recording for more than half of the racing time. The burden of ventricular arrhythmias recorded in the remaining 59 athletes is shown in Table 3. During the race, athletes reached a peak heart rate of 98% (91-105) of the maximal theoretical heart rate. A minority of athletes (5%) showed more than 100 premature ventricular beats (PVBs) or couplets (5%) during the entire recording that started the day before the race and ended after the race. Triplets or non-sustained ventricular tachycardia were not recorded in any athletes. During the race, 14 (24%) athletes showed ≥1 PVBs and

1 showed 2 couplets, but in only 4 (7%) of them the PVBs (always isolated) were distinctively exercise-induced while in the remaining 10 the arrhythmic burden decreased or remained unchanged compared with the resting period.

Echocardiography

Left ventricular echocardiographic data before and after the race are reported in Table 4. After the race, LV end-diastolic and end-systolic diameter and LV end-systolic volume index were significantly smaller as compared with baseline ($p<0.005$), whereas LV absolute volumes did not change. Left ventricular EF did not significantly differ before and after the race ($p=0.48$) as well as E/e' ratio ($p=0.26$). Left ventricular GLS and twisting did not differ at the end of the race.

Right ventricular dimensional and functional data collected before and after the race are presented in Table 5. After the race, no significant differences were found in RV inflow and outflow tract dimensions and in RV areas. RV function, estimated by RVFAC, TAPSE and RV s', remained substantially unchanged after the race. No increase in pulmonary arterial systolic pressure was found after the race ($p<0.001$). Similarly, RV GLS, RV free wall longitudinal strain and segmental strain did not change. Supplementary table 1 reports the results of the sub-analysis comparing the main clinical findings in males and females.

DISCUSSION

In this study we analyzed the acute effects of an ultra-marathon on the electrical and mechanical function of the heart in master athletes (≥40-year-old). We performed 12-lead resting ECG and standard and advanced echocardiography before and after the race; moreover, we recorded a single-lead ambulatory ECG before and during the competition. The main findings of this study were: i) traditional and advanced echocardiography did not demonstrate an acute damage to the LV; ii) RV dysfunction was not demonstrated after the ultramarathon in any athlete and also advanced parameters of RV function were unchanged at the finish line; iii) relevant ventricular arrhythmias were not recorded during the ultramarathon in any athlete.

The acute impact of strenuous exercise on the left ventricle

The increasing participation of athletes, and particularly master athletes, in endurance and ultra-endurance races in the last years has led to a growing number of studies investigating the acute effects of this discipline on the heart. Some evidence suggests that the physiological demands of maintaining a high cardiac workload for a prolonged time may result in a transient cardiac dysfunction, i.e. a form of exercise-induced 'cardiac fatigue' (21, 22). Some studies showed that LVEF was mildly impaired in the immediate post-exercise period following an endurance race (23, 24) but this finding was no confirmed by other investigations (25, 26). In the present study that focused on master athletes we found that LV function, assessed by LVEF, LV s' velocity and also LV GLS, did not significantly change after the ultramarathon. The discrepancies among the studies may be explained by the differences in methods, type of race, age and training status of participants (21). A recent meta-analysis, including studies that used advanced imaging techniques found a significant overall reduction in LV GLS and twisting after the races (27). The decline in LV twist reflected the reduced systolic contraction as well as the

reduced elastic recoil during untwist in early diastole(28).In fact, LV twist reflects the amount of energy stored in the myocardium during systolic contraction which is then subsequently released during diastole (29). Conversely, in a cohort of non-elite male marathon runners who completed the London marathon, LV strain, strain rates, rotation, rotation rates and torsion remained unaltered (30). In agreement with this study, we observed no significant change in GLS and LV twisting in our population after completing the ultra-race. A possible explanation is that we enrolled older individuals: indeed, exercise results in increased augmentation of torsion parameters in response to load or stimulus, but this effect is attenuated with aging(31).

The acute impact of strenuous exercise on the right ventricle

A meta-analysis found that prolonged endurance exercise does not have an impact on LV function while RV systolic function is reduced (32). Indeed, although initial experiences focused mainly on LV adaptations to training, substantial structural and functional adaptations of the RV have been more recently documented, particularly in endurance disciplines (33). It has been hypothesized that endurance events may lead to transient RV injury, but repetitive hits in the long-term may result in irreversible RV dysfunction and propensity to ventricular arrhythmias (so-called “exercise-induced arrhythmogenic cardiomyopathy”) (34). In our study, we found that RV dimensions and function remained substantially unchanged after the race. Notably, RV function was evaluated both by traditional and advanced echocardiography and the lack of a reduction of RV strain, a sensitive and early measure of RV dysfunction in different settings (35, 36), further strengthens the study. In contrast to our findings, RV myocardial dysfunction has been observed after very prolonged endurance exercise (10, 37, 38). The impact on RV function may depend on exercise intensity: the harder the effort, the greater the RV pressure demands and the larger the proportional difference between the demands placed on the RV and

the LV (39, 40). According to our findings, a 50-km marathon is not long enough to cause RV dysfunction. In line with this hypothesis, Oxborough et al.(41) observed no significant changes before and after the race in RV systolic function, estimated by RVFAC and TDI parameters, in 35 runners (age range 18–50 years) participating in the London marathon. Conversely, Neilan et al.(42) demonstrated echocardiographic abnormalities after the Boston marathon, with increased RV dimensions and decreased RV systolic function and free-wall RV longitudinal strain. However, differences exist between our study and that by Neilan et al: indeed, compared to athletes enrolled in our study, runners of the Boston marathon had a higher body mass index (23±3 vs. 20.3±2.6 kg/m^2) and showed increased post-race exercise pulmonary pressures.

The acute impact of strenuous exercise on the ECG and ventricular arrhythmias

The effects of ultra-endurance sport activity on the heart rhythm and on the ECG have not been entirely understood, although an electrical instability of the ventricular myocardium and right-sided acute changes in ECG were found in athletes after endurance races (43-45). The potential pro-arrhythmic effect of prolonged participation in intensive exercise has been a long-standing debate (46). Long-term and high levels of endurance exercise have been associated with the development of atrial fibrillation (47), increased coronary artery calcification (48), and unexplained myocardial fibrosis (10): therefore, a higher prevalence of ventricular arrhythmias is expected in master athletes. Approximately 10% of young athletes and up to 30% of master athletes have >10 isolated PVB on 24-h ambulatory monitoring (5, 49, 50). The prevalence of middle-aged athletes engaged in endurance or ultra-endurance mountain races with one or more PVBs at a pre-race 1-minute ECG recording was low (0.5%)(43). In our study, neither supraventricular nor sustained ventricular arrhythmias were detected at ambulatory ECG monitoring started the day before the race and continued for the entire duration of the ultramarathon.

During the race, 14 (24%) athletes showed ≥1 PVBs and 1 showed 2 couplets, but in only a minority of them the PVBs were distinctively exercise induced (i.e. 7%). In agreement, other studies have reported the absence of ventricular arrhythmias in male endurance athlete during marathon race with the number of PVBs decreasing significantly during and 1 hour after the marathon (51, 52). Notably, our research group demonstrated that, after a 120 Km high-altitude ultra-trail race, the prevalence of PVBs increases by six times after the run, in parallel with the prolongation of the QT interval (43). In the present study that enrolled participants in a shorter competition (50 Km) we demonstrated no relevant arrhythmias even in the presence of a small prolongation of the QTc interval, further strengthening the theory that the duration and the type of race rather than the sports discipline itself may have a significant impact on cardiac function.

Finally, the present findings were found in non-professional competitive athletes: therefore, while these data demonstrate that this type of race does not have detrimental effects on cardiac function and arrhythmias in master athletes, the present results cannot be generalized to professional athletes and to non-athletes running this races, in which a progression in terms of type, intensity and training volume is needed to obtain the beneficial effects of exercise and to prevent potential negative consequences on the cardiovascular system.

Limitations

This study has some limitations. First, the data were collected before and after the race, immediately at the finish line. The lack of a control 1 week after the race represents a limitation of this study: however, biventricular dysfunction was not found in this study and, as a consequence, the evaluation of normalization of a pathological finding was not needed; furthermore, long-term follow-up was not performed because the evaluation of the chronic effects of the ultra-endurance exercise was beyond

the scope of the study. Future researches are needed to clarify the long-term sequelae of endurance exercise in master athletes, investigating the effects of different type of competitions and the impact of age and years of sports practice. A single-lead ECG monitoring of 24-30 hours was performed in all athletes applying a small device which did not interfere with running and allowed us to monitor ECG from the day before the race to the end of the ultramarathon in all athletes. However, the evaluation of the morphology of ventricular arrhythmias is important to evaluate the site of origin and the arrhythmogenic mechanism (53-55): therefore, the lack of a 12-lead ECG monitoring represents a limitation of this study. Although cardiac magnetic resonance is able to characterize in details myocardial size and function, it has not been used in this study, primarily because of the logistic difficulties to perform scans immediately after a race in almost 70 athletes. However, in this study biventricular myocardial function was analyzed by speckle-tracking echocardiography: this advanced echocardiographic technique demonstrated to be sensitive to detect early myocardial dysfunction in different clinical scenarios (36, 56). For logistical reasons, we also did not collect blood samples for markers of cardiac damage such as troponin and BNP. Finally, the athletes enrolled in this study were all Caucasians and results cannot be generalized to athletes of different ethnicity.

CONCLUSIONS

Interest and participation in recreational and competitive endurance races have significantly increased over the last decades, with a growing number of older participants. However, some concerns exist about the potential negative cardiovascular effects induced by ultra-endurance races, particularly in master athletes. In this study, we evaluated at the same time pre- and post- race 12-lead ECG and standard and advanced echocardiography and recorded an ambulatory ECG before and during the race in a population of non-professional master athletes. We found that a 50-km ultramarathon did not have

a significant impact on left and right ventricular function and no ventricular arrhythmias were elicited during the competition, refusing the theory of acute negative cardiac effects for this discipline in this specific population.

Acknowledgments

The authors wish to thank the organizers of the Terre di Siena Ultramarathon, the University of Siena, and Medigas srl dealer RootiRx® for Italy for their support.

Conflicts of interest:

Nothing to disclose.

FIGURE LEGEND

Figure 1. Main findings of the study, demonstrating normal biventricular function before and after the race and absence of relevant ventricular arrhythmias.

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Word count

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Table 1. Demographic characteristics of the study population

Variables	
Age, years	47.9±7.8
Males, n (%)	47 (69)
Hours of training per week	6.7±4.4
Years of training	11.9±8.2
Duration of marathon race, hours	5.3±7.6
Family history CAD, n (%)	10(15)
Family history SCD, n (%)	0(0)
Height, cm	173±8
Weight, kg	71±11
BSA, m^2	1.8±0.17

CAD, coronary artery disease; SCD, sudden cardiac death; BSA, body surface area.

Table 2. Twelve-lead electrocardiographic measurements collected pre-race and at the finish line after the race

Variables	Pre-race	Post-race	P value
Resting heart rate, bpm	61±8	85±14	<0.0001
PR interval, ms	157±24	156±20	0.49
QRS duration, ms	91±15	89±9	0.12
R wave amplitude in V1, mV	0.20±0.13	0.26±0.16	<0.001
Prominent R wave, n (%)	1(1.5)	2(3)	0.50
LVH (isolated voltage criteria), n (%)	22(32)	17(25)	0.37
RVH (isolated voltage criteria), n (%)	2(3)	6(9)	0.10
R wave V5-6, mV	1.88±0.61	1.82±0.57	0.21
S wave V1, mV	0.98±0.40	1.01±0.41	0.41
R V5-6/S V1 ratio	2.2±1.1	1.8±0.5	<0.01
Early repolarization, n (%)	11(16)	13(19)	0.42
QT duration, ms	406±32	359±36	<0.001
QTc duration, ms	406±18	423±20	<0.001
T wave amplitude, mV	0.57±0.29	0.59±0.26	0.48
TWI, n (%)	4(6)	2(3)	0.08
ST segment depression, n (%)	2(3)	2(3)	1.0

LVH, left ventricular hypertrophy; RVH, right ventricular hypertrophy; TWI, T-wave inversion.

Table 3. Holter ECG monitoring data obtained before and during the entire duration of the race.

Variables	
Min HR, bpm	41(38-45)
Max HR, bpm	172(161-182)
Max HR/Max theoretical HR, %	98(91-105)
Number of PVBs/24h, n	46±148
≥1 PVB(s)/24 hours, n/%	31(53%)
≥100 PVBs/24 hours, n/%	5(5%)
Polymorphic PVBs, n/%	12(20%)
≥1 PVB(s) during the race, n/%	14(24%)
Exercise-induced PVBs*, n/%	4(7%)
≥1 couplet(s), n/%	3(5%)
≥1 couplet(s) during the race, n/%	1(2%)
≥1 triplet(s), n	0
≥1 triplet(s) during the race, n	0
≥1 NSVT(s), n	0
≥1 NSVT(s) during the race, n	0

PVB: premature ventricular beat; NSVT: non-sustained ventricular tachycardia. * Occurrence of PVBs only during exercise or increase in the burden of PVBs/hour.

Table 4. Standard and advanced echocardiographic data obtained for the left ventricle before and after the race in master ultramarathon runners.

Echocardiographic variables	PRE-RACE	POST-RACE	P values
LV end-diastolic diameter, mm	47.4±4.1	46.3±4.0	<0.05
LV end-systolic diameter, mm	27.7±4.5	26.2±4.2	<0.005
Interventricular septum, mm	9.7±1.3	9.8±1.2	0.10
Posterior wall, mm	9.4±1.0	9.5±0.9	0.40
RWT	0.40±0.05	0.41±0.05	<0.05
LV end-diastolic volume, mL	109.4±27.3	109.1±24.4	0.91
LV end-diastolic volume index, mL/m^2	59.7±12.7	59.3±10.4	0.75
LV end-systolic volume, mL	43.3±13.1	42.5±11.7	0.47
LV end-systolic volume index, mL/m^2	23.8±6.1	21.9±6.3	<0.05
LV ejection fraction, %	60.6±6.1	61.2±5.8	0.48
E/A ratio	1.33±0.44	0.95±0.39	<0.001
s' velocity, cm/s	0.12±0.06	0.13±0.06	0.46
E/e' ratio	6.1±1.8	5.8±2.1	0.26
Speckle-tracking echocardiographic parameters			
LV global longitudinal strain, %	-19.9±2.9	-19.0±4.0	0.067
LV TTP longitudinal strain, ms	356±41	337±38	<0.001
Twisting, °	12.2±5.6	11.1±4.6	0.22

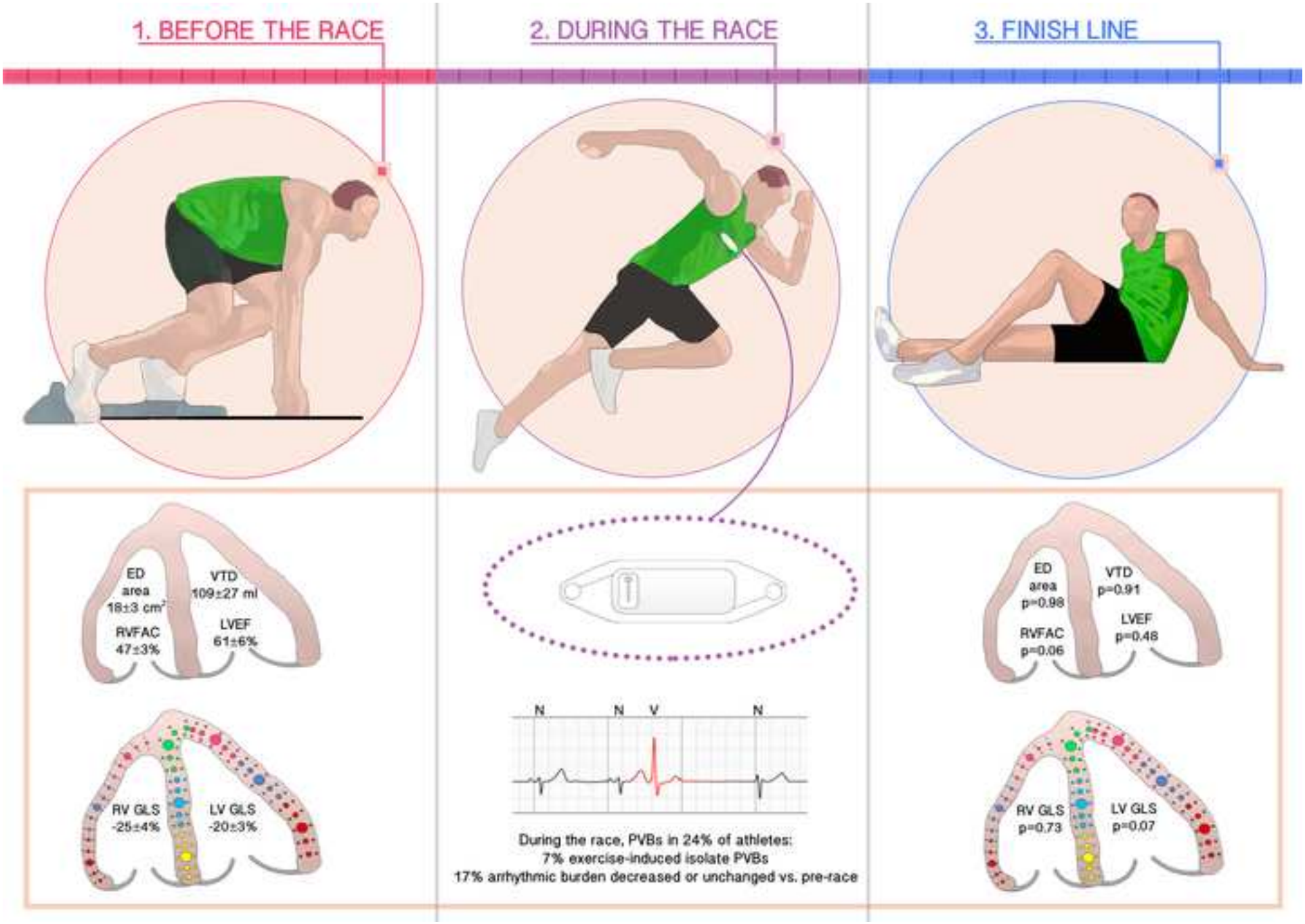
LV left ventricular; RWT, relative wall thickness; TTP, time-to-peak.

Table 5. Standard and advanced echocardiographic data obtained for the right ventricle before and after the race in master ultramarathon runners.

Echocardiographic parameters	PRE-RACE	POST-RACE	P value
RVOT PLAX, mm	31.9±4.4	32.2±3.8	0.55
RVOT PLAX index, mm/m^2	17.5±2.2	17.7±1.8	0.54
RVOT PSAX proximal diameter, mm	30.4±4.2	30.7±4.0	0.64
RVOT PSAX proximal diameter index, mm/m^2	16.7±2.2	16.9±2.1	0.62
RVOT PSAX distal diameter, mm	24.8±3.5	24.8±3.2	0.97
RVOT PSAX distal diameter index, mm/m^2	13.6±1.8	13.7±2.1	0.83
RV basal diameter, mm	38.3±3.9	37.2±4.1	<0.05
RV mid-cavity diameter, mm	29.5±3.9	28.8±4.1	0.20
RV diastolic area, cm^2	18.1±3.1	18.0±2.7	0.98
RV systolic area, cm^2	9.5±1.7	9.4±1.8	0.60
RV Fractional area change, %	47.0±3.9	48.2±4.5	0.058
TAPSE, mm	24.1±3.1	24.0±3.6	0.95
s', m/s	0.16±0.03	0.16±0.04	0.80
PASP, mmHg	22±5	21±4	0.94
Pulmonary velocity acceleration time, ms	148±25	134±21	<0.001
IVC, mm	17.7±2.9	16.6±3.7	<0.05
Speckle-tracking echocardiographic parameters			
RV GLS, %	-20.1±3.6	-19.8±3.9	0.42
RV FW basal strain, %	-22.7±6.1	-22.0±6.4	0.30
RV FW mid-cavity strain, %	-25.8±5.2	-25.3±6.3	0.62
RV FW apical strain, %	-27.3±6.3	-27.3±6.8	0.98
RV FW GLS, %	-25.2±4.8	-24.9±5.8	0.73
TTP longitudinal strain, ms	351±35	332±43	<0.005

RVOT, right ventricular outflow tract; PLAX, parasternal long-axis view; RV, right ventricular; TAPSE, tricuspid annular plane systolic excursion; PASP, pulmonary artery systolic pressure; IVC, inferior vena cava; GLS, Global longitudinal strain; FW free wall; TTP, time-to-peak.

Figure 1



Supplementary table 1. Comparison between male and female competitive athletes running a 50-km ultramarathon.

Variables	Males (n = 47)	Females (n = 21)	p value
PVBs/24 Hours	38±147	66±154	0.37
Isolated PVBs during the race	1±23	5±57	<0.01
Pre-race LV ejection fraction, %	60.3±4.5	59.7±10.9	0.75
Post-race LV ejection fraction, %	59.9±4.5	63.5±7.3	0.02
Delta LV ejection fraction			0.39
Pre-race LV GLS, %	-19.4±2.6	-21.0±3.0	0.03
Post-race LV GLS, %	-18.0±4.0	-20.9±2.9	0.003
Delta LV GLS			0.35
Pre-race RV Fractional area change, %	47.9±4.1	46.3±4.0	0.16
Post-race RV Fractional area change, %	48.3±3.4	48.0±6.2	0.80
Delta RV fractional area change			0.91
Pre-race RV FW GLS, %	-24.5±4.9	-26.9±4.7	0.06
Post-race RV FW GLS, %	-24.2±4.8	-26.6±7.5	0.12
Delta RV FW GLS			0.48

PVBs, premature ventricular beat; LV, left ventricular; GLS, global longitudinal strain; RV, right ventricular; FW, free wall.

ELECTROCARDIOGRAPHY

Left ventricular hypertrophy was defined based on Sokolow-Lyon criteria voltage while right ventricular hypertrophy was defined as R-wave amplitude in V_1 + S-wave amplitude in V_5> 10.5 mm (11). We used R-wave voltage in lead V_5-V_6 and S-wave voltage in lead V_1 to calculate the R/S ratio. The R-wave was defined as prominent when R/S ratio was ≥1 (12). T-wave inversion (TWI) was defined as negative T-waves >1 mm in depth in at least 2 consecutives leads in anterior, lateral, inferolateral or inferior leads (excluding leads III, aVR and V_1) (11). ST- segment depression was defined as ≥0.05 mV in depth relative to the isoelectric PR segment in two or more continuous leads (11). Early repolarization is defined as elevation of the QRS-ST junction (J point) by ≥0.1mV often associated with a late QRS slurring or notching (J wave) affecting the inferior and/or lateral leads (11).