European Journal of Applied Physiology (2026) 126:1449–1461
https://doi.org/10.1007/s00421-025-06008-5

ORIGINAL ARTICLE

Exercise-induced ventricular arrhythmias and subclinical ischemia risk in firefighters: exploratory results from a pilot study

Nuray Demiralp[1] · Serdar Akyel[2] · Hürmüz Koç[3] · Ahmet Öztürk[4]

Received: 18 April 2025 / Accepted: 23 September 2025 / Published online: 2 October 2025

Abstract

Aim This pilot study aimed to systematically evaluate exercise-induced electrocardiographic (ECG) responses in professional firefighters and to explore the association between premature ventricular complexes (PVCs) and myocardial ischemia in this high-risk occupational group.

Method This pilot cross-sectional study enrolled 21 male firefighters (mean age 43.4 ± 7.18 years) from a single municipal fire department. Participants underwent comprehensive cardiovascular assessment including anthropometric measurements, biochemical analyses (lipid profile, testosterone), submaximal exercise testing (Bruce protocol), and 24-h Holter ECG monitoring. Statistical analyses included Mann–Whitney U tests and effect size calculations.

Results No exercise-induced ST-segment changes indicative of myocardial ischemia were observed. However, PVCs were detected in 33% of participants (7/21), with exercise testing revealing 18 simple and 2 multiform PVCs, while Holter monitoring recorded 25 simple and 1 multiform PVC. PVC-positive firefighters were significantly older (median 49 vs. 40 years, $p = 0.019$, $r = 0.514$). Mean exercise capacity was 12.45 METs, with 81% achieving moderate fitness levels. Post-exercise heart rate recovery (HRR1: 24 ± 11.5 bpm; HRR2: 35.4 ± 11.5 bpm) showed normal patterns.

Conclusion The findings of this pilot study indicate the need for larger-scale investigations, supported by advanced diagnostic modalities, to clarify the clinical relevance of exercise-induced premature ventricular complexes (PVCs) in firefighters. Although no ischemic changes were observed, the presence of subclinical coronary artery disease cannot be definitively

Communicated by Stephen Ives.

Nuray Demiralp and Serdar Akyel have contributed equally to this work.

✉ Nuray Demiralp
ndemiralp@kastamonu.edu.tr

Serdar Akyel
drserdarakyel@hotmail.com

Hürmüz Koç
hurmuzkoc@gmail.com

Ahmet Öztürk
ahmetozturk@erciyes.edu.tr

1 Bozkurt Vocational School of Higher Education, Civil Defence and Firefighting Program, Kastamonu University, Kastamonu, Türkiye

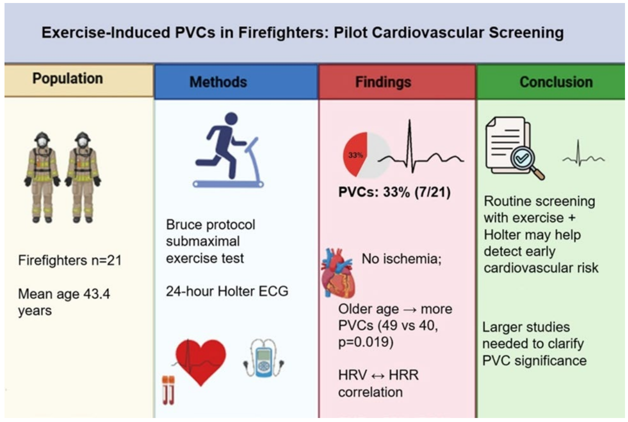
2 Department of Cardiology, Faculty of Medicine, Kastamonu University, Kastamonu, Türkiye

3 Faculty of Sport Sciences, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye

4 Department of Biostatistics, Faculty of Medicine, Erciyes University, Kayseri, Türkiye

excluded. These results provide a meaningful preliminary foundation for developing targeted screening approaches to improve early cardiovascular risk detection in high-physical-demand occupational groups.

Graphical abstract



Keywords Electrocardiography · Premature Ventricular Complexes · Firefighters · Exercise Test · Occupational Health

Introduction

Firefighting is a high-risk profession in which numerous physical and psychological stress factors pose significant threats to firefighters' health. The physical demands of firefighting are characterized by substantial activation of the cardiovascular, metabolic, and hormonal systems (Bode et al. 2021; Smith et al. 2016). During fire suppression activities, recorded physiological responses include heart rates exceeding 95% of the maximum (188–190 beats per minute) and high oxygen consumption rates (33.6–49.0 mL/kg/min), indicating pronounced activation of the sympathoadrenal axis. These findings highlight the significant physiological stress experienced during firefighting operations (Al-Zaiti et al. 2015; Gledhill and Jamnik 1992; Horn et al. 2013; Pluntke et al. 2019).

In addition to anxiety caused by unpredictable conditions, a sense of critical time urgency, extreme temperatures, fire smoke, toxic gases, and a heavy workload, firefighters are also burdened by the weight of personal protective equipment (approximately 25 kg), including self-contained breathing apparatus. These factors contribute to excessive physiological responses and significant activation of the cardiovascular system. Numerous studies have demonstrated that sudden cardiac events are the leading cause of duty-related deaths among firefighters (Fahy et al. 2008; Kales et al. 2007; Rodrigues et al. 2018; Smith et al. 2013). A review of the literature reveals that approximately 50% of on-duty firefighter fatalities are attributed to sudden cardiac events (Fahy et al. 2017). This proportion of duty-related deaths is significantly higher compared to police officers (22%), other emergency medical service providers (11%), and work-related fatalities across all occupations (15%) (Maguire et al. 2014; Fatalities among volunteer and career firefighters 2006).

Exercise testing in firefighters is used to ensure sufficient physical capacity for managing the strenuous demands of fire suppression and to identify individuals with potential undiagnosed heart disease (Fahy et al. 2008). Understanding the physiological responses to exercise stress testing in firefighters can provide insight into the occurrence of adverse cardiac events frequently experienced in this profession. However, due to the technical challenges of obtaining ECG data during actual fire suppression, alternative feasible testing methods have been explored, including studies on ECG responses to fire alarms, treadmill exercise testing, and ECG data collected during simulated firefighting scenarios (Al-Zaiti et al. 2015; Bjurö et al. 2004). Previous research has reported significant ECG abnormalities which indicate myocardial ischemia, along with notable ECG changes during such assessments (Carlén et al. 2019; Smith et al. 2019). Considering that various cardiovascular diseases such as arrhythmias, ventricular hypertrophy, and electrolyte imbalances are associated with abnormal ECG morphological alternations, monitoring these changes is particularly crucial for high-risk professionals (Brás et al. 2013; Paiva et al. 2016).

Exercise testing in firefighters is used to ensure sufficient physical capacity for managing the strenuous demands of fire suppression and to identify individuals with potential undiagnosed heart disease. Among the parameters of exercise testing, the duration is the most important variable within the loading components, such as the intensity, duration, and frequency of exercise. For instance, it has been shown that both ST segment depression and ST segment elevation predict cardiovascular risk and mortality independently of clinical risk factors in both symptomatic and asymptomatic individuals (Bruce et al. 1980; Hristopher et al. 1999). This study aims to examine myocardial ischemia findings during exercise testing and 24-h ECG monitoring in firefighters and investigate their relationship with premature ventricular contractions (PVCs). In particular, ST segment changes and abnormal ECG findings observed during exercise may provide valuable data for predicting cardiovascular risks. The study focuses on the hypothesis that PVCs may be triggered by myocardial ischemia, potentially increasing the risk of sudden cardiac events. The findings obtained through exercise tests and ECG monitoring are considered an important preventive strategy to help firefighters maintain both their occupational performance and minimize health risks.

The present study was designed as a pilot investigation to assess the feasibility of evaluating exercise-induced ventricular arrhythmias and their potential link with subclinical myocardial ischemia in professional firefighters. Although exploratory in nature, the findings aim to inform the methodological framework and hypothesis generation for future larger-scale cohort studies.

Method

Participants were recruited on a voluntary basis from a municipal fire department employing 80 full-time professional firefighters. Study announcements were made at all relevant fire stations, and 21 firefighters who met the inclusion criteria were enrolled in the study. In accordance with the study protocol, individuals with a history of chronic illness ($n = 3$) and those who did not meet the participation criteria for the exercise test ($n = 5$) were excluded from the study. All participants were active-duty professional firefighters with a minimum of 5 years of service. Eligibility for participation was determined through medical screening and responses to the Physical Activity Readiness Questionnaire (PAR-Q). Inclusion criteria required the absence of any known cardiovascular disease, no regular use of cardiac medications, and negative responses to all items on the PAR-Q.

Before undergoing physical tests and measurements, participants were assessed using the Physical Activity Readiness Questionnaire (PAR-Q) to identify any health conditions that might prevent their participation. This seven-item questionnaire is used to determine whether individuals have medical needs or health conditions that could pose a risk before engaging in physical performance tests and exercise applications. If a participant answered "yes" to any of the seven items, they were excluded from physical activity participation (Whitfield et al. 2017).

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the XXX University Clinical Ethics Committee (2023-KAEK-145). Written informed consent was obtained from all participants. This study has been conducted in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for reporting cross-sectional research.

Anthropometric measurements

Height was measured using a stadiometer (SECA; Seca Instruments Ltd, Hamburg, Germany) with a precision of ± 0.1 mm while participants stood with their heels together, body weight evenly distributed on both feet, and torso in an anatomical position. Body weight was measured using a digital scale (Tanita BC-545, Tanita Corp, Tokyo, Japan) with a precision of ± 0.05 kg. Participants were required to be barefoot and wear lightweight sportswear (e.g., shorts and a t-shirt) during the measurement. Body mass index (BMI) was calculated using the formula "body weight/height^2" (kg/m^2). Waist circumference was measured using a measuring tape at the umbilicus level while participants stood upright with a relaxed abdomen.

Biochemical measurements

To determine cardiometabolic risk factors, blood samples were analyzed for fasting blood glucose (FBG), glycated hemoglobin (HbA1c), total cholesterol (Total-C), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), triglycerides (TG), alanine aminotransferase (ALT), and aspartate aminotransferase (AST). Reference ranges for blood analyses were determined based on the guidelines published by the Turkish Society of Endocrinology and Metabolism (TEMD), including the Adrenal and Gonadal Disorders Guide, Diabetes Mellitus and Complications Diagnosis, Treatment, and Follow-up Guide, and the Dyslipidemia Diagnosis and Treatment Guide (Turkish Endocrinology and Metabolism Association 2022, 2021a). According to these reference values for adult males, HbA1c: ≤ 5.7% (normal); 5.7–6.4% (at risk); Total cholesterol: > 200 mg/dL (at risk); LDL cholesterol: > 130 mg/dL (at risk); HDL cholesterol: < 40 mg/dL (at risk); Triglycerides: ≥ 150 mg/dL (at risk); and Fasting blood glucose: ≥ 110 mg/dL (at risk). Blood samples for Total Testosterone (TT) analysis were collected between 08:00–10:00 AM, as recommended by the Adrenal and Gonadal Disorders Guide published by TEMD. The standard reference range for adult males was used in accordance with the guidelines. TT levels between 300–1000 ng/dL were considered normal, while values below 300 ng/dL were classified as low TT (Turkish Endocrinology and Metabolism Association 2021b).

Exercise test

The submaximal treadmill Bruce protocol was administered to assess cardiorespiratory endurance. The treadmill was initiated at a speed of 2.74 km/h (1.7 mph) with a 10% incline, and the incline was increased by 2% every three minutes. The test was terminated when the participant reported an inability to continue due to fatigue, pain, sudden changes in the monitored electrocardiogram, or any other adverse events (Bruce et al. 1980; Foster et al. 2008). At each three-minute incline increment, participants' real-time heart rates and perceived exertion levels were recorded. The total duration of the test, measured in minutes, was recorded as the "T" test score. Maximal heart rate (HRmax) was calculated using the Karvonen formula (220 – age).

The Target Heart Rate (THR) was calculated using the formula:

$$\text{THR} = (\text{HR max} - \text{HR rest}) \times 0.70) + \text{HR rest}$$

where HRmax is determined by 220 – age, HRR is calculated as HRmax – HRrest, and 70% THR is computed as (0.70 × HRR) + HRrest.

For male participants, VO_2max was estimated using the Bruce Protocol formula:

$$VO_{2\,max} = 14.8 - (1.379 \times T) + (0.451 \times T^2) - (0.012 \times T^3)$$

During the test, participants' heart rate and rhythm were continuously monitored using a 12-lead electrocardiogram (ECG) by a cardiology specialist and medical personnel. Systolic and diastolic blood pressure were measured every three minutes using a stethoscope and sphygmomanometer (Erka Perfect Aneroid, Germany).

The National Fire Protection Association (NFPA) recommends a minimum cardiorespiratory fitness capacity of approximately 42 mL/kg/min (12 metabolic equivalents, METs) for firefighters to safely perform their duties. Based on their physical fitness levels, firefighters were categorized into three groups: low fitness level: < 12 METs, moderate fitness level: 12–14 METs, and high fitness level: > 14 METs (National Fire Protection Association 2007).

24-hour 12-lead Holter ECG monitoring

After completing the exercise test, firefighters were allowed to cool down and rehydrate in the rest area. Once this process was completed, they changed into clean clothing, and ECG electrodes were attached by a cardiology nurse. The electrode cables were securely placed on cleansed areas of the torso and properly connected to the monitor. Firefighters were instructed to continue their daily activities (e.g., eating, sleeping) while wearing the 12-lead Holter monitor. However, they were advised to refrain from firefighting duties or engaging in strenuous activities during the monitoring period. After electrode placement, firefighters were required to wear the monitor for 24 h.

Heart rate variability (HRV) analysis

HRV analysis was conducted using electrocardiography (ECG) data recorded over a 24-h period with a portable Holter monitor worn by participants. The analysis of Holter recordings was performed by a specialist cardiologist, who removed artifacts, ectopic beats, and erroneous measurements to ensure data accuracy. The time-domain HRV parameters obtained from Holter data were analyzed based on reference ranges reported in the literature:

SDNN ≥ 100 ms: Represents normal cardiac autonomic activity over 24-h measurements.

SDANN ≥ 70 ms: Indicates adequate long-term HRV.

rMSSD ≥ 20 ms: Clinically significant indicator of parasympathetic activity.

pNN50 ≥ 4%: Represents the lower threshold of parasympathetic activity in a healthy population (Shaffer and Ginsberg 2017).

ECG analysis

The recorded ECG data were examined by a specialist cardiologist, and prior to analysis, artifacts, erroneous measurements, and abnormalities such as extrasystoles were removed. The QTc interval was calculated using Bazett's formula [$QTc = QT/\sqrt{(RR)}$], and reference values indicating that QTc values between 350 and 460 ms are considered normal regardless of gender were taken into account (Moss 1993). The normal reference ranges were accepted as 120–200 ms for the PR interval, 60–110 ms for the QRS duration, and < 90° for the QRS-T angle (Surawicz et al. 2009). After ECG recordings were completed, they were processed using an appropriate ECG software program incorporating arrhythmia detection, QRS-T angle analysis, and ST episode identification algorithms. The cardiology specialist reviewed arrhythmias and ST segment deviations identified by the software. ST-segment analysis, QRS-T angle assessment, and PVC detection were conducted during the exercise test and recovery period, with all data flagged as abnormal by the program transferred to a computerized database for further examination. ST-segment changes indicating myocardial ischemia, including ST depression and ST elevation, were analyzed based on the ST Depression Morphology and Diagnostic Criteria, ST Elevation Morphology and Diagnostic Criteria and Premature Ventricular Complex

(PVC) Diagnostic Criteria. PVCs on the ECG were defined as QRS complexes lasting ≥ 0.12 s without a preceding P wave. High-grade PVCs were classified as frequent (> 10 per minute), multifocal, consecutive PVCs (≥ 2 in a row, including ventricular tachycardia), or R-on-T type PVCs, which were identified during the exercise and recovery phases. Artifact-free 12-lead ECG data were selected from each 24-h monitoring record and printed for baseline ECG analysis by the cardiologist. The analysis included heart rate, rhythm, intervals (PR, QRS, QTc), axes (P, QRS, T, QRS-T angle), and ST-T wave changes.

Statistical analysis

Data analysis was performed using IBM SPSS Statistics software (version 23, IBM Corp., Armonk, NY, USA). A p-value of < 0.05 was considered the threshold for statistical significance in all analyses.

The normality of data distribution was assessed using the Shapiro–Wilk test and visual methods, including histograms and quantile–quantile (Q–Q) plots. Continuous variables were expressed as mean ± standard deviation ($\bar{X} \pm SD$) if normally distributed, or as median (minimum–maximum) if not. Categorical variables were reported as frequency (n) and percentage (%).

Between-group comparisons for continuous variables were performed using the Mann–Whitney U test due to non-normal data distribution, with effect sizes (r) calculated to quantify the magnitude of differences. Effect sizes were interpreted according to Cohen's guidelines ($r < 0.10$ = negligible, $0.10 \leq r < 0.30$ = small, $0.30 \leq r < 0.50$ = medium, and $r \geq 0.50$ = large). In addition, Spearman correlation analysis was used to examine the relationships between variables.

Results

Table 1 presents the demographic, anthropometric, and biochemical characteristics of the study participants. The participants' ages ranged from 34 to 58 years, with a mean age of 43.4 ± 7.18 years. Systolic blood pressure (SBP) values ranged from 90 to 130 mmHg, with a mean of 111.9 ± 11.23 mmHg, while diastolic blood pressure (DBP) ranged from 60 to 85 mmHg, with a mean of 75.47 ± 7.22 mmHg. The mean resting heart rate (RHR) was recorded as 69.4 ± 6.02 beats per minute. Regarding the lipid profile, the mean high-density lipoprotein cholesterol (HDL-C) level was 52.6 ± 10.4 mg/dL, with 2 participants classified as at-risk. The mean low-density lipoprotein cholesterol (LDL-C) level was 127.8 ± 26.0 mg/dL, with 10 participants classified as at-risk. The mean total cholesterol (Total-C) level was 204.3 ± 34.3 mg/dL. The mean triglyceride (TG) level was 166 ± 224.9 mg/dL. Fasting blood glucose (FBG) ranged from 60 to 164 mg/dL, with a mean of 99.9 ± 24.1 mg/dL, while HbA1c levels ranged from 4.5 to 6.3 mg/dL, with a mean of 5.39 ± 0.43 mg/dL. The mean total testosterone level was 308 ± 87.3 ng/dL, with 12 participants falling below the reference range (Table 1).

Table 1 Anthropometric and Cardiovascular Parameters of Firefighters

Parameters	Minimum	Maximum	X	SD	Risk n (%)
Age (year)	34	58	43.4	7.18	
Height (cm)	167	188	176	0.05	
Weight (kg)	68	98.4	84.7	7.54	
BMI (kg/m^2)	22.72	33.45	24.7	2.67	
BMI Category	n %				
Normal	4 (%19)				
Overweight	15 (% 71.4)				
Obese	2 (%9.5)				
SBP (mm/Hg)	90	130	111.9	11.23	
DBP mm/Hg)	60	85	75.47	7.22	
Resting HR (bpm)	57	80	69.4	6.02	
HDL-C (mg/dL)	32	79	52.6	10.4	2 (9.52)
LDL-C (mg/dL)	95	165	127.8	26.0	10 (47.6)
Total-Cholesterol (mg/dL)	147	259	204.3	34.3	13 (61.9)
Triglycerides (mg/dL)	49	968	166[a]	224.9	11 (52.3)
Fasting blood glucose (mg/dL)	60	164	99.9	24.1	4 (19.04)
HbA1c (mg/dL)	4,5	6,3	5.39	0.43	3 (14.2)
Total Testosterone (ng/dL)	173	499	308	87.3	12 (57.1)

SBP Systolic Blood Pressure; *DBP* Diastolic Blood Pressure; *RHR* Resting Heart Rate; *BMI* Body Mass Index; *HDL-C* High-Density Lipoprotein Cholesterol; *LDL-C* Low-Density Lipoprotein Cholesterol; *HbA1c* Hemoglobin A1c

Table 2 Exercise Test Parameters of Firefighters

Parameters	Minimum	Maximum	X	SD
Exercise duration (min)	6.5	14	9.95	1.68
Max Speed (km/h)	5.5	8	6.90	0.53
HR max (bpm)	138	192	160	12.55
HRR1 (bpm)	5	43	24	11.5
HRR2 (bpm)	15	60	35,4	11.5
MET	9.54	14.79	12.45	1.16
MET Classification	n %			
Low	1 (%4.8)			
Moderate	17 (%81)			
High	3 (%14.3)			

HRR1 heart rate recovery at 60 s; *HRR2*: heart rate recovery at 120 s. *MET* Metabolic Equivalent

Table 3 ECG Interval Axis and HRV Analysis of Firefighters

Parameters	Minimum	Maximum	X	SD	Abnormalities (n, %)
PR Interval (ms)	122	182	149.04	13.85	
QRS Duration (ms)	68	110	88.47	11.43	1 (%4.8)
QTc Interval (ms)	373	440	401.09	15.80	
QRS-T Angle (°)	1	33	17.80	7.98	
RR (ms)	651	1014	828.52	83.0	
RRsd (ms)	119	251	156.61	96.96	
SDDN (ms)	56	134	83.8	17.6	
SDAN (ms)	107	242	159.05	35.2	
rMSSD (ms)	16	62	33.6	12.91	
pNN50%	1	21	9.85	7.40	

PR PR interval; *QRS* QRS duration; *QTc* Corrected QT interval; *RR* Mean RR interval; *RRsd* Standard deviation of RR intervals; *SDDN* Standard deviation of daytime NN intervals; *SDAN* Standard deviation of nighttime NN intervals; *rMSSD* Root mean square of successive differences; *pNN50* Percentage of NN intervals > 50 ms

Table 2 presents the exercise test parameters of firefighters. The mean exercise duration was determined to be 9.95 ± 1.68 min. The maximum heart rate (HRmax) reached during exercise ranged between 138 and 192 bpm, with a mean of 160 ± 12.55 bpm. Metabolic equivalent (MET) values were recorded between 9.54 and 14.79, with a mean of 12.45 ± 1.16. Based on MET classification, 81% of participants were categorized as having a moderate fitness level. Regarding post-exercise heart rate recovery parameters, the first-minute recovery (HRR1) was recorded at an average of 24 ± 11.5 bpm, while the second-minute recovery (HRR2) was calculated as 35.4 ± 11.5 bpm.

In Table 3, the participants' PR interval ranged between 122 and 182 ms, with a mean value of 149.04 ± 13.85 ms. The QRS duration varied between 68 and 110 ms, with a mean of 88.47 ± 11.43 ms, and one participant (4.8%) was found to have abnormal values for this parameter. The QTc interval ranged from 373 to 440 ms, with a mean of 401.09 ± 15.80 ms. The QRS-T angle varied between 1° and 33°, with a mean of 17.80 ± 7.98°.

Regarding participants' heart rate variability (HRV) parameters, the RR interval (RR, ms) ranged from 651 to 1014 ms, with a mean value of 828.52 ± 83.0 ms. The standard deviation of the RR interval (RRsd, ms) varied between 119 and 251 ms, with a mean of 156.61 ± 96.96 ms. The standard deviation of the NN interval (SDNN, ms) ranged from 56 to 134 ms, with a mean of 83.8 ± 17.6 ms. The standard deviation of the NN interval averages (SDANN, ms) varied between 107 and 242 ms, with a mean of 159.05 ± 35.2 ms. The rMSSD (ms) ranged from 16 to 62 ms, with a mean of 33.6 ± 12.91 ms, while the pNN50 (%) parameter, representing the percentage of successive NN interval differences exceeding 50%, ranged between 1 and 21, with a mean of 9.85 ± 7.40.

According to Table 4, a total of 18 simple PVCs and 2 multiform PVCs were observed during exercise, whereas these values were recorded as 25 and 1, respectively, during Holter monitoring. Clinically significant findings such as ventricular tachycardia, R-on-T PVCs, ST segment changes

Table 4 Arrhythmia and Myocardial Ischemia Markers of Firefighters

	During Exercise	Holter ECG Monitoring
Arrhythmia Types	n total (number)	n total (number)
Simple PVC	18	25
Multiform PVC	2	1
Ventricular Tachycardia	0	0
R-on-T PVC	0	0
ST Segment Depression (≥ 1 mm)	0	0
ST Segment Elevation (≥ 1 mm)	0	0
Abnormal ORS-T Angle (> 45°)	0	0

PVC Premature Ventricular Contraction; *R-on-T PVC* Premature ventricular contraction occurring on the T wave; *ST Segment Depression/Elevation* Change in the ST segment ≥ 1 mm from baseline; *QRS-T Angle* Spatial angle between ventricular depolarization (QRS) and repolarization (T wave) vectors

(≥ 1 mm depression or elevation), and abnormal QRS-T angles (> 45°) were not observed in either condition.

In Table 5, the ages of firefighters ranged from 39 to 58 years, with maximum heart rates between 138 and 172 bpm. The MET values, which indicate exercise capacity, were measured between 9.54 and 14.76. The number of PVCs detected during exercise varied between 0 and 12, while the PVC count recorded during Holter monitoring ranged from 0 to 6. Additionally, firefighters 1, 2, and 3 exhibited post-exercise heart rate recovery (HRR1) values below 12 bpm at the first minute. Notably, firefighters 1 and 2 experienced recurrent PVC episodes (Multiform PVC) (Table 5) (Figs. 1, 2).

In Table 6, Comparative analyses between firefighters with and without PVCs revealed no statistically significant differences in most physiological and cardiovascular parameters, except for age, which demonstrated a large effect size ($r = 0.514$, $p = 0.019$). Medium effect sizes were observed for systolic blood pressure ($r = 0.313$, $p = 0.151$), diastolic blood pressure ($r = 0.376$, $p = 0.085$), and HRR1 ($r = 0.367$, $p = 0.093$), although these did not

Table 5 Firefighters with Positive Premature Ventricular Complex (PVC)

Firefighter	Age	Max HR	HRR1	MET	Exercise PVC	Holter ECG PVC
1	49	153	**9**	14.76	12 2 (Multi PVC)	5 1 (Multi PVC)
2	39	172	**6**	12.14	6	0
3	52	138	**5**	9.54	0	6
4	45	168	35	12.14	0	5
5	58	142	19	12.14	0	2
6	47	154	23	12.14	2	1
7	49	172	30	13.3	0	6

PVC Premature Ventricular Contraction; *Max HR* Maximum Heart Rate; *HRR1* Heart Rate Recovery at 60 s; *MET* Metabolic Equivalent; *Multi PVC* Multiple premature ventricular contractions observed in succession

Bold values indicate HRR1 <12 bpm, a threshold associated with adverse cardiovascular outcomes as reported by Hristopher et al. (1999)

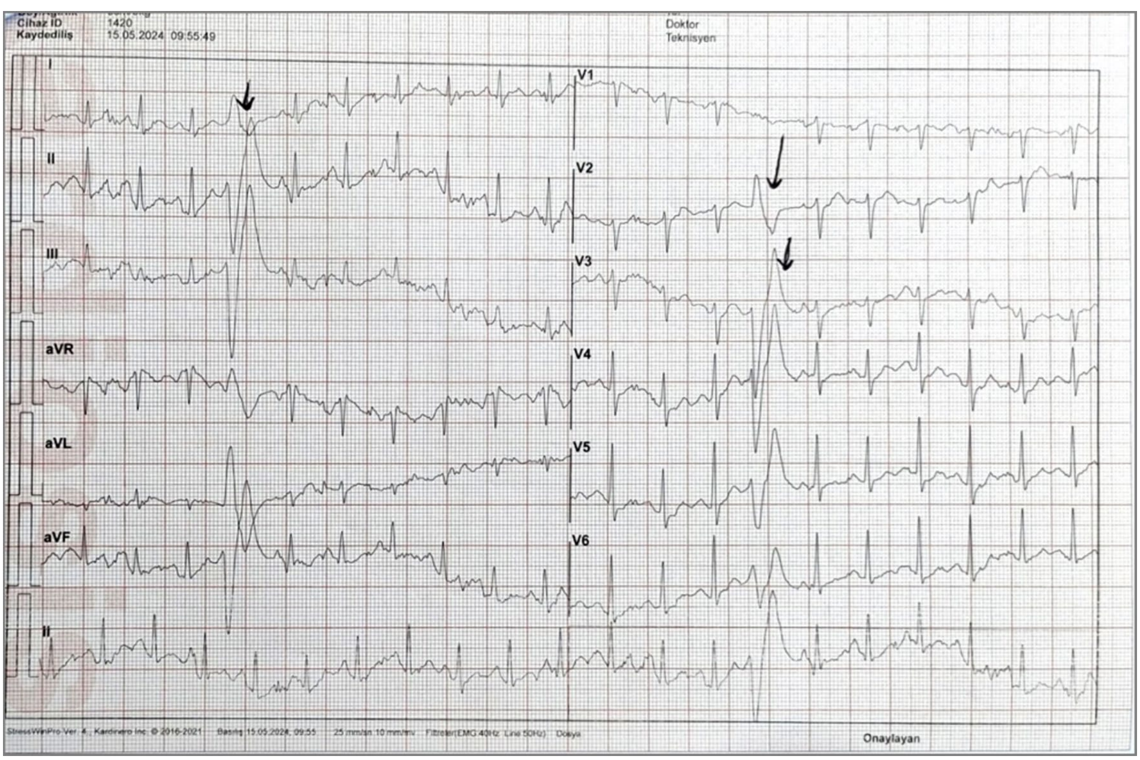


Fig. 1 Unifocal premature ventricular complex detected on a 12-lead ECG during the exercise test

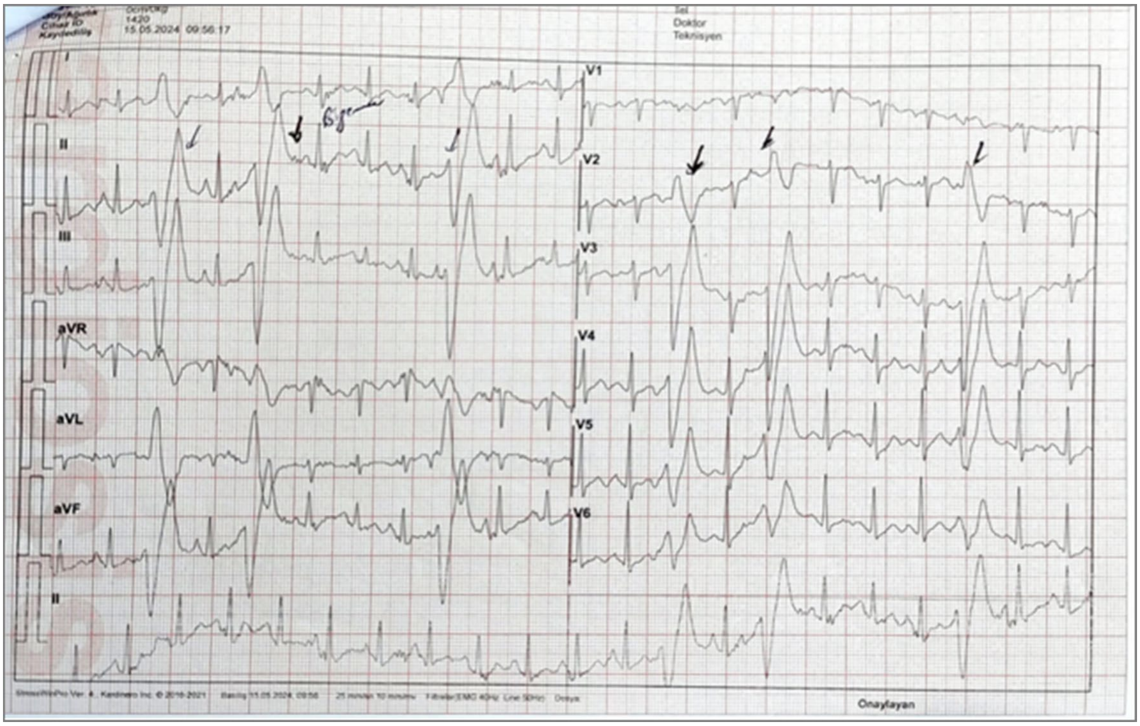


Fig. 2 Bigeminy premature ventricular complex detected on a 12-lead ECG during the exercise test

Table 6 Descriptive Statistics, Median Differences, and Effect Sizes Between PVC Groups

Variables	Group	N	Median	Min	Max	Median Difference	Effect Size *(r)*	Interpretation	*p* value
Resting HR (bpm)	Negative	14	72.5	57	80	– 3.00	0.033	Negligible	0.880
	Positive	7	69.0	60	78				
SBP (mmHg)	Negative	14	110.0	90	130	10.00	0.313	Medium	0.151
	Positive	7	120.0	110	130				
DBP (mmHg)	Negative	14	72.5	60	85	7.50	0.376	Medium	0.085
	Positive	7	80.0	70	85				
Exercise Duration (min)	Negative	14	9.75	8.5	14.0	0.25	0.008	Negligible	0.969
	Positive	7	10.0	6.5	11.5				
Max Speed (km/h)	Negative	14	6.8	6.8	8.0	0.00	0.143	Small	0.513
	Positive	7	6.8	5.5	8.0				
HRmax (bpm)	Negative	14	159.0	144	192	– 5.00	0.131	Small	0.550
	Positive	7	154.0	138	172				
MET	Negative	14	12.14	12.14	14.79	0.00	0.000	Negligible	1.000
	Positive	7	12.14	9.54	14.79				
HRR1 (bpm)	Negative	14	27.5	7	43	– 8.50	0.367	Medium	0.093
	Positive	7	19.0	5	35				
HRR2 (bpm)	Negative	14	36.5	15	60	2.50	0.163	Small	0.455
	Positive	7	39.0	19	42				
Age (years)	Negative	14	40.0	34	56	9.00	0.514	Large	**0.019**
	Positive	7	49.0	39	58				

Mann–Whitney U Test. The sections highlighted in bold indicate statistically significant differences ($p < 0.05$). r values are interpreted according to Cohen's guidelines: $r < 0.10$ = negligible, $0.10 \leq r < 0.30$ = small, $0.30 \leq r < 0.50$ = medium, and $r \geq 0.50$ = large effect. Values with $p < 0.05$ are presented in bold reach statistical significance. Effect sizes for other parameters were in the negligible-to-small range.

According to the correlation results presented in Table 7, strong and statistically significant correlations were found among heart rate variability (HRV) parameters, including pNN50, rMSSD, SDNN, and SDANN (e.g., pNN50 and rMSSD: $r = 0.932$, $p < 0.01$). Additionally, a positive and significant relationship was observed between HRR1 and HRR2 ($r = 0.572$, $p < 0.01$). When the moderate correlations were examined, testosterone was found to be related to pNN50 ($r = 0.381$) and rMSSD ($r = 0.299$); however, these relationships did not reach statistical significance. A moderate correlation was detected between RR_sd and HRR1 ($r = 0.473$, $p < 0.05$).

Discussion

Exercise-induced premature ventricular complexes (PVCs) are associated with an increased risk of cardiovascular disease in asymptomatic adult males. Myocardial ischemia due to cardiovascular disease can reduce coronary blood flow and impair exercise performance (Dzikowicz and Carey 2020; Refaat et al. 2021). Therefore, exercise-induced PVCs may serve as an early indicator of cardiovascular disease. The aim of this study is to determine whether exercise-induced PVCs in firefighters, a population with a high cardiovascular risk, are associated with myocardial ischemia and reduced exercise performance. In this study, exercise-induced PVCs were detected in three firefighters, while Holter ECG monitoring identified PVCs in six firefighters.

A study examining the 12-h ECG responses in firefighters following a simulated fire suppression activity reported potentially significant arrhythmias specific to myocardial ischemia. In this study, seven firefighters exhibited the onset of ventricular ectopy, while five firefighters displayed new ECG findings suggesting possible or definite myocardial ischemia (Smith et al. 2019). Al-Zaiti et al. investigated ECG changes during and for two hours following a live fire suppression drill in 42 firefighters with a mean age of 31 ± 9 years. Pathological ST-segment changes were detected in 11 participants during fire suppression, and such changes were also observed in two additional firefighters during the recovery period. Additionally, prolonged QT intervals were reported in half of the firefighters during fire suppression (Al-Zaiti et al. 2015). In contrast to the existing literature, the present study revealed that the majority of firefighters had normal ECG findings, and no evidence of myocardial ischemia was found.

A study conducted with a total of 112 firefighters found that, despite maintaining a normal sinus rhythm, more than half exhibited at least one high-risk ECG factor, including abnormal sympathetic tone (elevated heart rate, 54%), abnormal repolarization (wide QRS-T angle, 25%), myocardial scarring (fragmented QRS, 24%), and myocardial ischemia (ST depression, 24%). Most firefighters tolerated the treadmill exercise stress test well (mean metabolic equivalent task [MET]: 11.8 ± 2.5); however, nearly one-third demonstrated abnormal stress test results, requiring further evaluation to rule out subclinical coronary artery disease (Al-Zaiti et al. 2015).

Hunter et al. examined electrocardiographic changes in 19 healthy male firefighters (mean age: 41 ± 7 years) before and after simulated fire suppression activities. Following fire suppression, a significant increase in tachycardia (mean 162 bpm) and ST depression, defined as a J-point depression of + 50 ms, was reported in ECG monitoring (Hunter et al. 2017). In the present study, upon analyzing the ECG findings of firefighters, only one firefighter was found to have a QRS duration below the reference range.

In another study conducted among firefighters, pathological myocardial ischemia was observed in 10 firefighters

Table 7 Correlations Between Physiological and Cardiovascular Parameters

	TT	BMI	HRR1	HRR2	MET	Age	pNN50	rMSSD	SDDN	SDAN	RR_mean
BMI	– 0.240										
HRR1	0.077	– 0.236									
HRR2	0.158	– 0.130	**0.572****								
MET	0.106	– 0.004	0.130	0.159							
Age	– 0.169	– 0.066	– 0.407	– 0.426	– 0.131						
pNN50	0.381	– 0.086	**0.471***	**0.474***	0.083	– 0.305					
rMSSD	0.299	– 0.080	**0.492***	0.336	0.038	– 0.232	**0.932****				
SDDN	0.006	– 0.019	0.363	0.204	0.123	0.166	**0.502***	**0.684****			
SDAN	– 0.086	0.197	0.282	– 0.166	0.165	0.060	0.350	**0.582****	**0.640****		
RR_mean	0.245	– 0.236	0.415	0.307	0.047	0.289	**0.608****	**0.612****	**0.672****	0.421	
RR_sd	0.033	0.020	**0.473***	– 0.024	– 0.196	– 0.056	**0.532***	**0.705****	**0.684****	**0.776****	**0.579****

Statistically significant Spearman correlation coefficients are presented in bold. Significance thresholds are denoted as follows: p<0.05; p<0.01 during exercise, with an average maximum ST-segment depression of 2.5 ± 1.3 mm. The mean MET value at which maximum ST-segment depression occurred during exercise was reported as 13.0 ± 1.7 (Dzikowicz and Carey 2021). In the present study, the average MET value was 12.45 ± 1.16, and no ST-segment depression was observed during the exercise test.

Proper heart rhythm and function rely on the critical balance between the sympathetic and parasympathetic branches of the autonomic nervous system. Exercise-induced PVCs are believed to result from an increased catecholaminergic state during physical activity (Fleg et al. 1985). Therefore, such depolarizations appear to be a physiological response to exercise. This is further supported by their lack of association with cardiovascular mortality. PVCs occurring during the recovery phase have been linked to insufficient vagal reactivation following exercise, similar to impaired heart rate recovery post-exercise. As demonstrated in this asymptomatic cohort, this mechanism appears to be independent of coronary heart disease (Frolkis et al. 2003; Fukuda et al. 2015).

The association of exercise-induced premature ventricular complexes (EI-PVCs) with myocardial ischemia among asymptomatic male firefighters provides additional evidence for the relationship between EI-PVCs and myocardial ischemia and suggests that EI-PVCs may serve as an early indicator of cardiovascular disease (Dzikowicz and Carey 2020). Exercise-induced PVCs have been linked to adverse cardiovascular outcomes. In another study, EI-PVCs were found to be associated with a 1.82-fold increase in cardiovascular event risk among asymptomatic individuals, which highlights the potential impact of autonomic dysfunction on HRR (Lee et al. 2017). In the present study, similar to the literature, firefighters 1, 2, and 3 were found to have HRR1 values below 12 bpm in the first minute following exercise. In particular, firefighters 1 and 2 exhibited recurrent PVC episodes ("Multiform PVC"). A review of the literature indicates that a reduction in heart rate of 12 beats per minute or less in the first minute post-exercise has been identified as an independent predictor of all-cause and cardiovascular mortality, even in asymptomatic individuals (Hristopher et al. 1999).

In asymptomatic individuals without heart disease, the presence of high-grade PVCs during the recovery phase, rather than during the exercise test itself, has been shown to predict long-term cardiovascular mortality, independent of clinical and other exercise test variables (Refaat et al. 2021). In the present study, Holter-ECG monitoring recorded 25 simple PVCs and 1 multiform PVC. However, PVCs were observed predominantly during exercise, with a smaller number occurring in the early recovery phase. While this pattern limits the direct prognostic interpretation of our findings, the detection of PVCs during the recovery phase underscores the necessity for long-term cardiac follow-up, particularly in high-risk occupational groups such as firefighters. In the general healthy population, the prevalence of PVCs ranges between 0 and 4% (Fleg et al. 1985; Bjerregaard 1982). However, a study conducted among on-duty firefighters reported a PVC prevalence of 11% (Carey and Bernard 2009). Similarly, in this study, PVCs were detected in 33% of firefighters, aligning with findings in the literature. This suggests that, compared with cohorts of similar age and socioeconomic status, firefighters may have a higher cardiovascular risk profile (Marcus 2020). Our findings highlight the potential contribution of occupational stressors and lifestyle factors to this disparity, underscoring the need for larger-scale prospective investigations.

In this pilot cohort, no ischemic ECG changes were detected on exercise testing or 24-h Holter monitoring, and Mann–Whitney U comparisons showed no significant differences in HRR or core HRV metrics between PVC-positive and PVC-negative groups, suggesting that exercise-induced PVCs are not invariably accompanied by overt autonomic impairment. Nonetheless, significant correlations between HRR1 and parasympathetic-sensitive HRV indices (pNN50, rMSSD), together with strong concordance among HRV measures, imply a role for vagal modulation in post-exercise recovery and in PVC occurrence even in the absence of ischemia (Hristopher et al. 1999; Zhang et al. 2024; Routledge et al. 2010). Given that the PVC-positive group was older and age correlated inversely with HRR, age-related autonomic/fitness factors may contribute; therefore, larger, sex-inclusive studies integrating HRV/HRR with exercise testing and advanced imaging are warranted to clarify the clinical relevance of PVCs and to inform generalizable screening strategies for firefighters.

In this study, exercise testing and Holter monitoring were conducted on firefighters to comprehensively assess the effects of intense physical stress on the cardiovascular system. These methods play a crucial role in the early detection of occupationally induced subclinical myocardial ischemia and arrhythmias and provide a critical tool for preventing cardiovascular events in high-risk populations, such as firefighters.

Working with a homogeneous sample group allowed for a specific evaluation of occupational risks. Additionally, the study focused on clinically critical parameters such as myocardial ischemia and exercise-induced premature ventricular contractions (EI-PVCs).

However, the limited sample size comprising 21 firefighters recruited from a total workforce of 80 within a single municipal fire department reduces both the statistical power and the generalizability of the findings. This constraint may also limit the study's capacity to detect low-prevalence cardiovascular events, such as exercise-induced arrhythmias and subclinical ischemia.

While the identification of isolated premature ventricular contractions (PVCs) during both exercise testing and ambulatory Holter monitoring provides preliminary insights into the arrhythmic burden in this cohort, the low event frequency observed should be interpreted within the context of the sample size and the participants' overall cardiovascular health.

Importantly, the absence of ischemic ECG changes—namely ST-segment depression or elevation—does not preclude the possibility of underlying subclinical or transient ischemia, particularly given the limited capacity of the current sample size to detect rare events. These findings likely reflect the relatively healthy and physically fit status of the included participants, all of whom met stringent inclusion criteria, including negative responses to all items on the PAR-Q and no prior history of cardiovascular disease or symptoms.

Given the exploratory nature of the study, these preliminary findings should be viewed as hypothesis-generating rather than confirmatory. Future investigations with larger, more diverse populations and more prolonged or stress-inducing monitoring protocols will be essential to validate the current observations and more accurately characterize the arrhythmogenic and ischemic profile of occupational populations such as firefighters. The study's inclusion of only male firefighters presents a limitation, as it prevents the assessment of cardiovascular risks among female firefighters. Furthermore, the lack of long-term follow-up data makes it impossible to evaluate the impact of the findings on cardiovascular mortality.

A notable limitation of the present study is the absence of comparison with gold-standard diagnostic modalities for ischemia, such as myocardial perfusion imaging or coronary computed tomography angiography. In the absence of these reference methods, it is not possible to definitively exclude subclinical ischemia, particularly in a physically active cohort where exercise tolerance may mask underlying pathology. Therefore, the lack of ischemic ECG findings should be interpreted with caution, and the diagnostic utility of exercise testing alone should not be overstated. While our findings suggest a low incidence of overt ischemic changes in this selected population, future studies incorporating multimodal imaging will be necessary to validate the accuracy and sensitivity of functional exercise testing in early ischemia detection.

This pilot study highlights a potential association between exercise-induced premature ventricular contractions (PVCs) and myocardial ischemia, underscoring the possible value of exercise testing and ECG monitoring in the early detection of subclinical cardiovascular risk among high-demand occupational groups such as firefighters. Integrating these non-invasive methods into routine screening protocols may help reduce occupational cardiovascular risks by enabling earlier identification of at-risk individuals.

Nonetheless, the limited sample size and exploratory design of this study restrict the generalizability of the findings and necessitate cautious interpretation. The absence of ischemic changes should not be taken as definitive exclusion of subclinical pathology. Despite these limitations, the study addresses an underexplored clinical domain and offers a scientific foundation for future research involving larger cohorts and comprehensive diagnostic strategies.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00421-025-06008-5.

Acknowledgements The authors extend their sincere gratitude to all the firefighters who participated in this study and to the relevant institutions and authorities for their technical support.

Author contributions All authors actively contributed to the design and planning of the study. The first draft of the manuscript was written by Nuray Demiralp, while the other authors provided comprehensive evaluations and revisions to previous versions during the review process. All authors have read and approved the final version of the manuscript.

Funding This study was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK) under project number 223S848.

Data availability The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest. This study was supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK, Project No: 223S848), however, the funding organization had no role in study design, data collection, analysis, interpretation, or manuscript preparation.

Ethical approval Approved by Kastamonu University Clinical Ethics Committee (Approval Number: 2023-KAEK-145). Informed consent was obtained from all participants.

References

Al-Zaiti S, Rittenberger JC, Reis SE, Hostler D (2015) Electrocardiographic responses during fire suppression and recovery among experienced firefighters. J Occup Environ Med 57(9):938–942. https://doi.org/10.1097/JOM.0000000000000507

Bjerregaard P (1982) Premature beats in healthy subjects 40–79 years of age. Eur Heart J 3(6):493–503. https://doi.org/10.1093/oxfordjournals.eurheartj.a061344

Bjurö T, Gullestad L, Endresen K, Nordlander M, Malm AR, Höglund L et al (2004) Evaluation of ST-segment changes during and after maximal exercise tests in one-, two- and three-vessel coronary artery disease. Scand Cardiovasc J 38(5):270–277. https://doi.org/10.1080/14017430410021606

Bode ED, Mathias KC, Stewart DF, Moffatt SM, Jack K, Smith DL (2021) Cardiovascular disease risk factors by BMI and age in

United States firefighters. Obesity 29(7):1186–1194. https://doi.org/10.1002/OBY.23175
Brás S, Fernandes JM, Cunha JPS (2013) ECG delineation and morphological analysis for firefighters tasks differentiation. Proc CBMS 2013 - 26th IEEE Int Symp Comput-Based Med Syst. 516–7. https://doi.org/10.1109/CBMS.2013.6627856.
Bruce RA, DeRouen TA, Hossack KF, Blake B, Hofer VR (1980) Value of maximal exercise tests in risk assessment of primary coronary heart disease events in healthy men: five years' experience of the seattle heart watch study. Am J Cardiol 46(3):371–378. https://doi.org/10.1016/0002-9149(80)90003-X
Carey MG, Bernard JMT (2009) High-resolution 12-lead electrocardiograms of on-duty professional firefighters: a pilot feasibility study. J Cardiovasc Nurs 24(4):261. https://doi.org/10.1097/JCN.0B013E3181A4B250
Carlén A, Gustafsson M, Åström Aneq M, Nylander E (2019) Exercise-induced ST depression in an asymptomatic population without coronary artery disease. Scand Cardiovasc J 53(4):206–212. https://doi.org/10.1080/14017431.2019.1626021
Dzikowicz DJ, Carey MG (2020) Exercise-induced premature ventricular contractions are associated with myocardial ischemia among asymptomatic adult male firefighters: implications for enhanced risk stratification. Biol Res Nurs 22(3):369. https://doi.org/10.1177/1099800420921944
Dzikowicz DJ, Carey MG (2021) Severity of myocardial ischemia is related to career length rather than age among professional firefighters. Workplace Health Saf 69(4):168–173. https://doi.org/10.1177/2165079920984080
Fahy RF, Leblanc PR, Molis JL (2008) Firefighter fatalities in the United States-2007. Natl Fire Prot Assoc
Fahy RF, Leblanc PR, Molis JL (2017) Firefighter fatalities in the United States-2016. Natl Fire Prot Assoc.
Fatalities among volunteer and career firefighters—United States, 1994–2004. JAMA. 2006;295(22):2594.
Fleg JL, Tzankoff SP, Lakatta EG (1985) Age-related augmentation of plasma catecholamines during dynamic exercise in healthy males. J Appl Physiol 59(4):1033–1039. https://doi.org/10.1152/jappl.1985.59.4.1033
Foster C, Porcari JP, Anderson J, Hare J, Slivka D, Ward A et al (2008) The talk test as a marker of exercise training intensity. J Cardiopulm Rehabil Prev 28(1):24–30. https://doi.org/10.1097/01.HCR.0000311504.41775.78
Frolkis JP, Pothier CE, Blackstone EH, Lauer MS (2003) Frequent ventricular ectopy after exercise as a predictor of death. N Engl J Med 348(9):781–790. https://doi.org/10.1056/nejmoa022353
Fukuda K, Kanazawa H, Aizawa Y, Ardell JL, Shivkumar K (2015) Cardiac innervation and sudden cardiac death. Circ Res 116(12):2005–2019. https://doi.org/10.1161/circresaha.116.304679
Gledhill N, Jamnik VK (1992) Characterization of the physical demands of firefighting. Can J Sport Sci 17(3):207–213. https://doi.org/10.1249/00005768-198904001-00032
Horn GP, Blevins S, Fernhall B, Smith DL (2013) Core temperature and heart rate response to repeated bouts of firefighting activities. Ergonomics 56(9):1465–1473. https://doi.org/10.1080/00140139.2013.818719
Hristopher C, Ole RC, Ugene E, Lackstone HB, Ashkow RJP, Laire C et al (1999) Heart-rate recovery immediately after exercise as a predictor of mortality. N Engl J Med 341(18):1351–1357. https://doi.org/10.1056/NEJM199910283411804
Hunter AL, Shah ASV, Langrish JP, Raftis JB, Lucking AJ, Brittan M et al (2017) Fire simulation and cardiovascular health in firefighters. Circulation 135(14):1284–1295. https://doi.org/10.1161/circulationaha.116.025711
Kales SN, Soteriades ES, Christophi CD, Christiani DC (2007) Emergency duties and deaths from heart disease among firefighters in the United States. N Engl J Med 356(12):1207–1215. https://doi.org/10.1056/NEJMOA060357
Lee V, Perera D, Lambiase P (2017) Prognostic significance of exercise-induced premature ventricular complexes: a systematic review and meta-analysis of observational studies. Heart Asia 9(1):14–24. https://doi.org/10.1136/heartasia-2016-010854
Maguire BJ, O'Meara PF, Brightwell RF, O'Neill BJ, Fitzgerald GJ (2014) Occupational injury risk among Australian paramedics: An analysis of national data. Med J Aust 200(8):477–480
Marcus GM (2020) Evaluation and management of premature ventricular complexes. Circulation 141(17):1404–1418. https://doi.org/10.1161/CIRCULATIONAHA.119.042434/ASSET/53CD3225-E96F-455E-A9D6-95B9232B50BD/ASSETS/GRAPHIC/CIRCULATIONAHA.119.042434.FIG06.JPG
Moss AJ (1993) Measurement of the QT interval and the risk associated with QTc interval prolongation: a review. Am J Cardiol 72(6):B23–B25. https://doi.org/10.1016/0002-9149(93)90036-C
National Fire Protection Association. NFPA 1582: Standard on Comprehensive Occupational Medical Program for Fire Departments [Internet]. 2007 [cited 2024 May 18]. Available from: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1582
Paiva JS, Rodrigues S, Cunha JPS (2016) Changes in ST, QT and RR ECG intervals during acute stress in firefighters: a pilot study. Annu Int Conf IEEE Eng Med Biol Soc 2016:3378–3381. https://doi.org/10.1109/EMBC.2016.7591452
Pluntke U, Gerke S, Sridhar A, Weiss J, Michel B (2019) Evaluation and classification of physical and psychological stress in firefighters using heart rate variability. Annu Int Conf IEEE Eng Med Biol Soc 2019:2207–2212. https://doi.org/10.1109/EMBC.2019.8856596
Refaat MM, Gharios C, Moorthy MV, Abdulhai F, Blumenthal RS, Jaffa MA et al (2021) Exercise-induced ventricular ectopy and cardiovascular mortality in asymptomatic individuals. J Am Coll Cardiol 78(23):2267–2277. https://doi.org/10.1016/j.jacc.2021.09.1366
Rodrigues S, Paiva JS, Dias D, Cunha JPS (2018) Stress among on-duty firefighters: an ambulatory assessment study. PeerJ 2018(12):e5967. https://doi.org/10.7717/PEERJ.5967/SUPP-1
Routledge FS, Campbell TS, McFetridge-Durdle JA, Bacon SL (2010) Improvements in Heart rate variability with exercise therapy. Can J Cardiol 26(6):303–312. https://doi.org/10.1016/S0828-282X(10)70395-0
Shaffer F, Ginsberg JP (2017) An overview of heart rate variability metrics and norms. Front Public Health 5:290215. https://doi.org/10.3389/fpubh.2017.00258
Smith DL, Barr DA, Kales SN (2013) Extreme sacrifice: sudden cardiac death in the US fire service. Extrem Physiol Med 2(1):1–9. https://doi.org/10.1186/2046-7648-2-6
Smith DL, DeBlois JP, Kales SN, Horn GP (2016) Cardiovascular strain of firefighting and the risk of sudden cardiac events. Exerc Sport Sci Rev 44(3):90–97. https://doi.org/10.1249/JES.0000000000000081
Smith DL, Horn GP, Fernhall B, Kesler RM, Fent KW, Kerber S et al (2019) Electrocardiographic responses following live-fire firefighting drills. J Occup Environ Med 61(12):1030. https://doi.org/10.1097/JOM.0000000000001730
Surawicz B, Childers R, Deal BJ, Gettes LS, Bailey JJ, Gorgels A et al (2009) AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram: part III: intraventricular conduction disturbances. Circulation 119(10):e235–e240. https://doi.org/10.1161/circulationaha.108.191095
Turkish Endocrinology and Metabolism Association. Dyslipidemia diagnosis and treatment guidelines. 2021. Available at: https://file.temd.org.tr/Uploads/publications/guides/documents/20211026164301-2021tbl_kilavuzb66456ad2f.pdf.

Turkish Endocrinology and Metabolism Association. Adrenal and gonadal diseases guideline. 2021 [cited 2023 Sep 10]. Available from: https://file.temd.org.tr/Uploads/publications/guides/documents/20210104142630-2021tbl_kilavuz72fa0dcdc2.pdf

Turkish Endocrinology and Metabolism Association. Diabetes Mellitus and Its Complications: Diagnosis, Treatment, and Follow-up Guidelines. 2022. Available at: https://file.temd.org.tr/Uploads/publications/guides/documents/diabetes-mellitus_2022.pdf.

Whitfield GP, Riebe D, Magal M, Liguori G (2017) Applying the ACSM preparticipation screening algorithm to U.S. adults: national health and nutrition examination survey 2001–2004. Med Sci Sports Exerc 49(10):2056–2063. https://doi.org/10.1249/MSS.0000000000001313

Zhang B, Jinbo Yu, Yizhang Wu, Li X, Xie X, Tao A, Yang B (2024) The significance of heart rate variability in patients with frequent premature ventricular complex originating from the ventricular outflow tract. Clin Cardiol 47(1):e24174. https://doi.org/10.1002/CLC.24174