T-Wave Variability Detects Abnormalities in Ventricular Repolarization: A Prospective Study Comparing Healthy Persons and Olympic Athletes

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Background: Sudden cardiac death in athletes is more common than in the general population. Routine screening procedures are performed to identify competitors at risk. A new Holter-based parameter analyzes variation of the ventricular repolarization (TVar). The aim of this study was to evaluate differences in electrocardiogram (ECG), Echo, and Holter (H) in competitive athletes compared to a healthy control group consisting of medical students (MS).

Methods: A total of 40 athletes (19 females, Olympic team, Luxembourg) and 40 MS (22 females) were examined by means of a resting ECG, treadmill exercise (TE), echocardiogram (Echo), as well as H recordings during a routine screening visit. To analyze TVar, a 20-minute H recording at rest (sampling rate 1000 per second) was performed. Moreover, heart rate variability (HRV) as well as HR turbulence (HRT) was computed.

Results: No differences in demographic variables were detected. Quantification of HRV detected a significant increase in the vagal component of autonomic cardiac modulation. In contrast, no differences for HRT were found. Echo parameter demonstrated a thicker septal wall without differences of the posterior wall. TVar values were normal in range, but did differ significantly between the two groups. No correlation between TVar and echo as well as Holter parameters was detected.

Conclusions: TVar was able to demonstrate significant differences in terms of alterations of ventricular activation. This might indicate an early change of myocardial repolarization representing a substrate for life-threatening arrhythmia. Larger studies on the predictive value of TVar including follow-up are necessary to confirm this preliminary finding.

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Sudden cardiac death (SCD) in athletes is more common than in the general population.^{1,2} Routine screening procedures are performed to identify competitors at high risk, but even with these not every competitor is filtered out. For an early identification of athletes with an increased risk for ventricular tachyarrhythmia (VT) and SCD, it would be helpful to develop noninvasive methods besides echocardiography (echo) and treadmill tests. In the past several years, a number of noninvasive risk

parameters such as heart rate variability (HRV), heart rate turbulence (HRT), deceleration capacity, T-wave alternans, and QT variability have become of increasing interest and have demonstrated their usage for patients with coronary artery disease (CAD).³

Recently, a new Holter-based parameter was invented and evaluated for its predictive power in patients with CAD, chronic myocardial infarction, and depressed ejection fraction (EF).³ This new

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parameter, T-wave variability (TVar), analyzes variations of the ventricular repolarization.

The aim of this study was to evaluate differences in electrocardiogram (ECG), echo, and Holter parameters in competitive athletes compared to a healthy control group consisting of medical students (MS).

METHODS

The study population for this investigation consisted of 80 healthy persons. A total of 40 athletes (Olympic swimming team Luxembourg, 19 females) and 40 MS (University of Bonn, 22 females) were examined. Each test person performed a treadmill exercise (TE), an echo, as well as a Holter recording (H) for 24 hours. Persons revealing any pathology in the ECG, echo, or treadmill test were excluded from H analysis.

End Points

The aim of this study was to analyze how many healthy persons were tested positive on the new Holter-based parameter, TVar, using the threshold for patients with CAD.¹ As secondary endpoints, we also evaluated differences in ECG, echo, and H in competitive athletes compared to a healthy control group consisting of MS. The test protocols were the same in Luxembourg and in Bonn.

Measurements of Treadmill Exercise

The goal of the treadmill exercise was to ensure that every test person was healthy, even in a forced stress situation. The blood pressure as well as the heart rate was measured during the exercise. Every test person showing pathologic alterations was excluded.

Echocardiographic Analysis

The goal of the echocardiogram was to ensure that no test person shows any pathology of the cardiac anatomy. Furthermore, the expected changes in left ventricular dimension were of interest. We analyzed left ventricular EF, diameters and volumes of the left ventricular in systole and in diastole, septal, and posterior thickness, diameter and volume of the left atrium, and the estimated pulmonary artery pressure. Persons demonstrating any valve disease exceeding grade one stage were excluded.

Holter Recordings and Processing

The ELA medical *SpiderView* (ELA Medical SORIN Group, Le Plessis-Robinson, France) Holter recorder with ELA medical SD flash card was used to record the ECG signals. These recorders were able to acquire the ECG data in a high-resolution mode, a sampling frequency of 1000 per second. A shielded 7-wire cable was used for recordings in high-resolution mode and for low-noise standard recordings. For the analysis of TVar, the standard electrodes (Blue Sensor) were placed in orthogonal X, Y, and Z lead configuration. After the recording period of 20 minutes in supine position without movement, the H recorder was switched to the standard recording for 24 hours.

After 24 hours, the ECG files of the first 20 minutes were converted to the standard H format defined by ISHNE (International Society for Holter and Noninvasive Electrocardiology). The SyneScope 3.10 software including the SyneTVar 3.10g software module (ELA Medical, SORIN Group, Le Plessis-Robinson, France) was used to process recorded ECG files and to perform the TVar analysis. The analysis is based on the vector magnitude VM ($VM = \sqrt{X^2 + Y^2 + Z^2}$), which was used as the primary lead. Only sinus beats are retained in the process, all nonsinus beats are excluded from the analysis.

Analyzing T-Wave Variability

For the analysis of TVar, the parameters were adjusted to the number of beats included in each segment ($Nb = 60$ beats), the beginning of the repolarization interval with 120 ms, and the noise parameter ($\leq 12 \mu V$). With a recording period of 20 minutes, the number of valid clusters should be at least three. For the analysis, the median of all median values was computed for further assessment.

Analyzing HRV Parameters

HRV parameters were analyzed according to the actual guidelines. The systems provide with all parameters of the time domain as well as of the frequency-domain method.

HRT

HRT parameters were computed according to Schmidt.⁴ HRT is expressed as T onset (O) and T slope (S).

Table 1. Echocardiography Parameters of Both Groups

	Students	Athletes	P Value	P Value (Corrected by Gender)
Septal wall (mm)	9.0 ± 1.4	9.8 ± 1.5	0.018	0.018
Posterior wall (mm)	9.2 ± 1.7	8.8 ± 1.6	0.28	0.28
Left atrium (mm)	33 ± 6	35 ± 5	0.08	0.08
Pulmonary artery pressure (mmHg)	17 ± 6	23 ± 4	0.0005	0.0005
LVEDD (mm)	48 ± 6	53 ± 5	<0.0001	<0.0001
LVESD (mm)	30 ± 5	35 ± 7	0.0002	0.0001
LVEDV (mL)	89 ± 30	127 ± 39	<0.0001	<0.0001
LVESV (mL)	32 ± 18	53 ± 25	<0.0001	<0.0001
LV mass (g)	152 ± 39	187 ± 56	0.0015	0.0005
LV EF (%)	67 ± 5	62 ± 8	0.0012	0.0014

LV = left ventricle; EDD = end-diastolic diameter; EDS = end-systolic diameter; EDV = end-diastolic volume; ESV = end-systolic volume; EF = ejection fraction.

QTc Duration

QTc parameters were calculated by the help of the system software provided.

Statistical Analysis

SAS (SAS Institute, Cary, NC) software calculated differences of the investigated parameters. A P value of less than 0.05 was considered statistically significant.

RESULTS

The athletes were younger (23 ± 5 vs 27 ± 6 years, $P < 0.009$), taller (179 ± 9 vs 173 ± 9 cm, $P < 0.003$), and gained more weight (71 ± 11 vs 67 ± 14 kg, $P = \text{ns}$). Body mass index was not significantly different (22 ± 3 vs 22 ± 3 kg/m²). Table 1 illustrates the differences in the echo parameters including evaluation of gender influence. Different outcomes in terms of autonomic modu-

lation are demonstrated in Table 2. The latter also provides data for gender comparison. The correlation between the TVar and echo as well as Holter parameter detected only nonsignificant results.

DISCUSSION

Actually, physical examination, treadmill testing, and echocardiography measurement represent the routine medical care for competitive athletes. These tests are performed to detect abnormalities, for example, hypertrophic cardiomyopathy, before they become clinically evident. An SCD in an athlete reflects a dramatic scenario watched by an incredible number of people, for example, during an ice hockey match or like during a European semi-cup final.

Often, changes in ventricular depolarization or even repolarization are accused to reflect an important mechanism in terms of the initiation of life-threatening arrhythmia. The actual investigation

Table 2. Holter-Derived Analysis

	Students	Athletes	P Value	P Value (Corrected by Gender)
Heart rate (min ⁻¹)	77 ± 7.2	66 ± 8.2	<0.0001	<0.0001
SDNN (ms)	168 ± 34	216 ± 60	<0.0001	<0.0001
LF/HF	3.5 ± 1.6	2.9 ± 1.4	0.07	0.05
TO (%)	-1.6 ± 4	-3.0 ± 5	NS	NS
TS (ms/RRI)	13 ± 10	14 ± 10	NS	NS
TVar (μV)	22 ± 7.9	25 ± 8.7	0.014	0.014
QTc (ms)	408 ± 20	409 ± 21	NS	NS

For HRV, only significant differences are shown. SDNN = standard deviation of all normal-to-normal intervals; LF = low-frequency peak; HF = high-frequency peak; TO = turbulence onset; TS = turbulence slope; RRI = R to R interval; TVar = T-wave variability.

was undertaken to evaluate whether the recently invented subtle computation of the T wave during a high-resolution recording (TVar) is able to detect differences between Olympic athletes and healthy MS. In the actual setting, none of the participants revealed a pathologic TVar value. But, some results were of interest: first, dimensions of the left ventricle (LV) differed like one would expect from professional exercise. Notably, only the septum but not the posterior wall was thicker in the competitors' group. In addition, EF differed, but still remained within a normal range. In terms of estimated pulmonary artery pressure, the students' group demonstrated a lower result than the Olympic group. This might be explained by an increased LV preload, enabling an instant increase in stroke volume during maximum exercise.

When comparing data of the Holter recording, a strong increase in the vagal component of the autonomic modulation could be demonstrated. The heart rate, standard deviation of all normal-to-normal intervals (SDNN), as well as the ratio of low and high frequency (LF/HF) were strongly different. None of the 80 individuals reached the main endpoint of the presented investigation, that is, positive results for TVar. Nevertheless, the Olympic athletes group clearly showed a higher TVar compared to the MS. This finding might reflect some early changes in repolarization of a "trained" left ventricular myocardium. Alterations quantified by TVar may indicate that oscillations in the electrical repolarization phase occur more often than ex-

pected. This fact is emphasized by the fact that QTc duration as well as gender did not alter the difference. Of note, TVar did not have correlation to any of the echo or Holter parameters.

Whether these alterations represent a harbinger for a horror scenario like SCD demands further investigations.

Limitations

This investigation reflects a single center with athletes consisting mainly of swimmers, that is, we did not examine other athletes like runners or even oarsmen. Moreover, we computed repolarization but not changes in depolarization only. Third, we did not perform a routine follow-up for several months. At least, as the authors are aware of, no event of all participants in the study happened since the beginning of the protocol.

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