

# The electrocardiographic “triangular QRS-ST-T waveform” pattern in patients with ST-segment elevation myocardial infarction: Incidence, pathophysiology and clinical implications<sup>☆,☆☆</sup>

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## Abstract

**Background:** A specific ECG pattern of presentation of ST-segment elevation acute myocardial infarction (STEMI), characterized by “triangular QRS-ST-T waveform” (TW), has been associated with poor in-hospital prognosis but longitudinal data on its incidence and clinical impact are lacking. We prospectively evaluated the incidence and prognostic meaning of the TW pattern in a cohort of consecutive STEMI patients.

**Methods:** All STEMI patients who presented within 12 h of symptoms onset and showed no complete bundle branch block or paced ventricular rhythm were included. The TW pattern was defined as a unique, giant wave (amplitude  $\geq 1$  mV) resulting from the fusion of the QRS complex, the ST-segment and the T-wave and showing a “triangular” morphology with a positive polarity in the leads exploring the ischemic region.

**Results:** Among 428 consecutive STEMI patients, 367 fulfilled the enrollment criteria. The TW pattern was identified in 5 of 367 patients (1.4%) on the admission ECG. This subset of STEMI patients with TW pattern significantly more often showed a left main coronary artery involvement (2/4, 50% vs 2/322, 0.6%;  $p < 0.001$ ), experienced ventricular fibrillation (5/5, 100% vs 35/362, 9.6%  $p < 0.001$ ), had cardiogenic shock (4/5, 80% vs. 14/362, 3.8%,  $p < 0.001$ ) and died during hospitalization (2/5, 40% vs 15/362, 4.1%  $p = 0.02$ ), compared with those with other ST-segment elevation ECG patterns.

**Conclusions:** The TW pattern is an uncommon ECG finding, which reflects the presence of a large area of transmural myocardial ischemia and predicts cardiogenic shock accounting for high in-hospital mortality. When present, this ECG pattern should prompt aggressive therapeutic strategies, including mechanical support of circulation.

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## Keywords:

Acute myocardial infarction; Cardiogenic shock; Electrocardiogram; ST-segment; Ventricular fibrillation

## Introduction

The elevation of the ST-segment is the electrocardiographic hallmark of acute transmural myocardial ischemia, known from 1920 after the first description of Pardee [1]. It

is typically characterized by J-point elevation, a domed ST-segment configuration and a T-wave that, initially positive, tends to invert during the subacute phase [2].

The electrocardiographic (ECG) patterns at admission of patients suffering ST-segment elevation myocardial infarction (STEMI) may show different duration of R wave, morphology of ST-segment elevation, polarity of the T wave and presence (or absence) of Q and S waves, mostly depending on the location, severity and duration of the ischemic injury, as well as on patients characteristics such as sex, age and body mass index [3].

Previous studies reported that specific STEMI ECG patterns such as the “tombstoning” and the “lambda-like”

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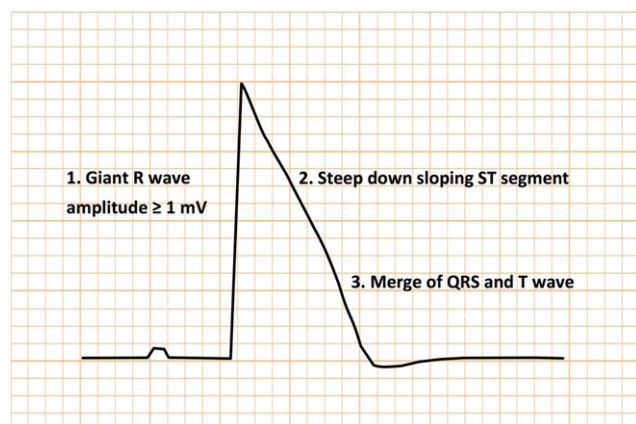


Fig. 1. Schematic representation of the triangular QRS-ST-T waveform.

pattern were identified as predictors of poor in-hospital prognosis [4–6]. The specific ECG pattern characterized by a “triangular morphology” was associated with an increased risk of on-admission ventricular fibrillation (VF) [7]; however, longitudinal data on its incidence and clinical impact in a consecutive population of patients with STEMI are lacking.

In the present study we focused on the “triangular QRS-ST-T waveform” (TW) pattern, which was herein defined as a unique, giant wave (amplitude  $\geq 1$  mV) resulting from the fusion of the QRS complex, the ST-segment and the T-wave and showing a “triangular” morphology with a positive polarity in the leads exploring the ischemic region. The study was designed to evaluate the incidence and acute clinico-prognostic impact of the TW pattern in a consecutive series of patients with STEMI.

## Material and methods

Between January 2015 and December 2016, we studied 428 consecutive patients (295 men, aged  $68 \pm 14$  years), admitted for STEMI to the Division of Cardiology, University hospital of Padova, Italy, which is a hub for primary percutaneous coronary interventions (PCI). Data about clinical and angiographic characteristics, treatment strategies and in-hospital clinical outcomes were collected.

According to the 2012 European Society of Cardiology guidelines [8], STEMI was diagnosed in case of 1) continuous chest pain for at least 20 min, 2) ST-segment elevation measured at the J point in at least two contiguous leads,  $\geq 0.25$  mV in men below the age of 40 years,  $\geq 0.2$  mV in men over the age of 40 years, or  $\geq 0.15$  mV in women in leads V2–V3 and/or  $\geq 0.1$  mV in other leads, in the absence of left ventricular hypertrophy or left bundle branch block, and 3) troponin I rise. The 12-leads ECGs (25 mm/s, 10 mm/mV, 0.05–150 Hz), that were acquired in two thirds of cases in the pre-hospital setting by the emergency medical service for early identification of STEMI, were prospectively collected and analyzed by 2 investigators (A.C., G.D.). The TW was defined as the presence of a giant R wave higher than 1 mV, followed by a steep down sloping ST segment, that concealing the T wave, lands to the isoelectric line, thus forming a triangular shape (Fig. 1).

Patients admitted over 12 h from symptoms onset and those with complete right bundle branch block, left bundle branch block or ventricular paced rhythm were excluded from the study. Discrepancies in ECG interpretation were resolved by consensus. The study complies with the Declaration of Helsinki, and the ethics review board of our institution approved the study protocol.

## Statistical analysis

Continuous variables were reported as mean  $\pm$  standard deviation and compared using the rank sum test because of the small size of TW subgroup. Categorical variables were reported as number and percentage and compared with the Fisher's exact test, as appropriate. A 2-tailed  $p < 0.05$  was considered statistically significant. All analyses were performed using SPSS 24 (SPSS Inc.; Chicago, IL).

## Results

Among the 428 patients, 367 (276 males, mean age  $64 \pm 14$  years) met the study inclusion criteria, while 61 were excluded because of late presentation ( $n = 51$ ), ventricular paced rhythm ( $n = 4$ ), left bundle branch block ( $n = 4$ ) or right bundle branch block ( $n = 2$ ).

The main clinical characteristics, ECG and angiographic findings, interventional procedures performed and in-hospital clinical outcomes of the overall study population are summarized in Table 1. On the first ECG, recorded a mean of  $150 \pm 108$  min from symptoms onset, ST-segment elevation was most commonly evident in the anterior leads V1–V4 ( $n = 140$ , 38.1%), followed by the inferior leads II/aVF/III ( $n = 130$ , 35.4%). The left anterior descending (LAD) was the most common culprit coronary artery ( $n = 147$ , 40.0%), while the left main (LM) was the least common ( $n = 4$ , 1.1%). Primary PCI was performed in 326 patients (88.8%). During hospitalization, 18 patients (4.9%) suffered cardiogenic shock, which was treated with intra-aortic balloon pump in 15 cases (4.1%) and extracorporeal membrane oxygenation (ECMO) in 10 (2.7%). In-hospital mortality was 4.6% ( $n = 17$ ).

Five patients (1.4%) presented with the TW pattern. The prevalence of TW was 10% among the 50 patients who presented within 60 min after symptoms onset versus 0% among those with a late presentation. No differences of the TW ECG pattern and the involved ECG leads were observed between ECG recordings obtained in the pre-hospital and in-hospital settings.

Clinical characteristics of this subset of patients are reported in Table 2. No patients had history of pre-infarction angina. At angiography, four patients had a single vessel disease, involving the proximal left coronary artery in three cases (LM in two patients and LAD in one) and proximal right coronary artery in one case. The remaining patient died from cardiogenic shock before cardiac catheterization. All patients experienced one or more episodes of VF at admission. Four patients developed at hospital admission a cardiogenic shock, which was treated with an ECMO device in three cases. Two of five patients died. Two clinical TW cases are briefly reported in Figs. 2 and 3.

Table 1  
Main characteristics of the study population.

| Population (n = 367)                                     |            |
|--|------------|
| Male, n (%)  | 276 (75.2) |
| Age (years), mean±SD                                     | 64 ± 14    |
| Onset to admission (min), mean±SD                        | 150 ± 108  |
| Risk factor and medical history                          |            |
| Arterial hypertension, n (%)                             | 233 (63.5) |
| Diabetes mellitus, n (%)                                 | 65 (17.7)  |
| Dyslipidemia, n (%)                                      | 157 (42.8) |
| Family history of CAD, n (%)                             | 135 (36.8) |
| Smoke, n (%)   | 117 (31.9) |
| Previous stroke, n (%)                                   | 19 (5.2)   |
| Malignancy, n (%)  | 8 (2.2)    |
| Severe COPD, n (%)                                       | 7 (1.9)    |
| Dementia, n (%)  | 10 (2.7)   |
| Previous AMI, n (%)                                      | 32 (8.7)   |
| Chronic kidney disease, n (%)                            | 33 (9.0)   |
| Electrocardiographic location of AMI                     |            |
| Anterior (V1–V4), n (%)                                  | 140 (38.1) |
| Anterior (V1–V4) and lateral (V5–V6, I, aVL), n (%)      | 44 (12.0)  |
| Lateral (V5–V6, I, aVL), n (%)                           | 22 (6.0)   |
| Inferior (II/aVF/III), n (%)                             | 130 (35.4) |
| Inferior (II/aVF/III) and lateral (V5–V6, I, aVL), n (%) | 20 (5.4)   |
| Posterior (V7–V9), n (%)                                 | 6 (1.6)    |
| Infarct-related coronary artery                          |            |
| Left main, n (%)   | 4 (1.1)    |
| Left anterior descending, n (%)                          | 147 (40.0) |
| Left circumflex, n (%)                                   | 27 (7.4)   |
| Ramus intermedius, n (%)                                 | 1 (0.3)    |
| Right coronary, n (%)                                    | 124 (33.8) |
| Multiple vessel, n (%)                                   | 25 (6.8)   |
| Unobstructed coronary artery, n (%)                      | 29 (7.9)   |
| Unknown, n (%)   | 10 (2.7)   |
| Revascularization strategy                               |            |
| Primary PCI, n (%)                                       | 326 (88.8) |
| Thrombolysis, n (%)                                      | 1 (0.3)    |
| Urgent CABG surgery, n (%)                               | 1 (0.3)    |
| Events in acute phase                                    |            |
| Cardiac arrest pre-revascularization, n (%)              | 40 (10.9)  |
| Cardiogenic shock, n (%)                                 | 18 (4.9)   |
| IABP, n (%)  | 15 (4.1)   |
| ECMO, n (%)  | 10 (2.7)   |
| Death during ICU stay, n (%)                             | 17 (4.6)   |

AMI, acute myocardial infarction; CABG, coronary artery bypass graft; CAD, coronary artery disease; COPD, chronic obstructive pulmonary; ECMO, extra corporeal membrane oxygenation; IABP, intra-aortic balloon pump; ICU, intensive care unit; PCI, percutaneous coronary intervention; SD, standard deviation.

STEMI patients with and without a TW pattern did not differ regarding age and gender. The subset of STEMI patients with TW pattern significantly more often showed LM coronary artery involvement (2/4, 50% vs 2/322, 0.6%;  $p < 0.001$ ), experienced VF (5/5, 100% vs 35/362,  $p < 0.001$ ), had cardiogenic shock (4/5, 80% vs. 14/362,  $p < 0.001$ ) and died during hospitalization (2/5, 40% vs 15/362  $p = 0.02$ ), compared with those with other ST-segment elevation ECG patterns.

## Discussion

The ECG represents one of the most useful tools for the diagnosis and localization of acute myocardial infarction

(AMI). ST-segment elevation in leads facing the area of ischemic injury is the ECG hallmark of transmural infarction, and its prompt identification plays an essential role for the acute management of affected patients [9]. Additionally, admission ECG offers the potential to provide helpful information about the prognosis of AMI patients. Our study focused on the “triangular” STEMI ECG pattern and showed that 1) this pattern was observed in 1.4% of consecutive patients admitted for STEMI to our PCI referral center; 2) it predicted a malignant prognosis as it was associated with in-hospital death due to cardiogenic shock.

### Definition of the “triangular” waveform

In the present study, we focused on the clinical course of STEMI patients presenting with a distinctive ECG pattern, defined as *triangular* QRS-ST-T waveform, which is characterized by a single, giant wave (amplitude  $\geq 1$  mV) resulting from the fusion of the QRS complex, the ST-segment and the T-wave and showing a “triangular” morphology with a positive polarity in the leads exploring the ischemic region.

This pattern should be distinguished from other specific ST-segment elevation ECG patterns reported in previous studies. It should not be confused with the “tombstoning” ECG pattern, which is observed in about 10–25% of STEMI patients, most often as a result of acute occlusion of proximal LAD [5,10]. The features of the tombstoning ECG are well described by Guo [10] and differ from those of the TW pattern with regard to the presence of an elevated, convex upward ST-segment, that connects a small and short R wave with a higher and broader T wave. This pattern has been associated with malignant ventricular arrhythmias and higher rate of acute complications [5], although this association was demonstrated in the “thrombolytic era” of myocardial infarction, before the advent of percutaneous revascularization therapy of AMI.

The TW pattern was previously referred as “*lambda-like*” pattern [6] and was associated with the development of VF during the acute phase of myocardial infarction [6,7]. In a multicenter 5-year case-control study, Aizawa et al. [7] reported that the “lambda-like/triangular” ST-segment pattern was significantly more prevalent among the selected population of STEMI complicated by VF (48%) compared with the control population of uncomplicated STEMI (4.1%).

Our prospective study confirms and extends prior observations by providing data (previously lacking) on the incidence of this ECG pattern among a series of consecutive STEMI patients and showing for the first time that it represents a strong ECG marker of impending cardiogenic shock.

### Incidence of the “triangular” ST-segment elevation

In our study, the TW pattern was uncommon (1.4% of cases), showing an annual incidence of 0.7% among our cohort of consecutive STEMI patients. The incidence could be underestimated by our study, if one considers the high risk of these patients to die from sudden cardiac death before



Table 2  
Details of the five patients with ST-segment elevation acute myocardial infarction showing the triangular QRS-ST-T waveform at presentation.

| Patient | Sex, age (years) | Risk factors           | Clinical presentation   | VF               | Time to first ECG | LVEF at admission | Culprit vessel | Cardiogenic shock | Acute Management                          | Peak TnI (ng/L) | Final Outcome        |
|---------|------------------|------------------------|-------------------------|------------------|-------------------|-------------------|----------------|-------------------|---|-----------------|----------------------|
| #1      | Male, 64         | Smoking, hypertension  | Chest pain, hypotension | Yes, before PCI  | 30 min            | 25%               | LMCA           | Yes               | PCI, ECMO, IABP, inotrope and vasopressor | 400,000         | Death (7th day)      |
| #2      | Female, 60       | Smoking, hypertension  | Chest pain, dizziness   | Yes, after PCI   | 5 min             | 31%               | LMCA           | Yes               | PCI, ECMO, IABP, inotrope and vasopressor | 203,100         | Discharge (25th day) |
| #3      | Male, 46         | Diabetes, dyslipidemia | Cardiac arrest          | Yes, before PCI  | 20 min            | 44%               | RCA            | Yes               | PCI, ECMO, inotrope and vasopressor       | 150,700         | Discharge (19th day) |
| #4      | Male, 75         | Hypertension           | Cardiac arrest          | Yes, before PCI  | 15 min            | 55%               | LAD            | No                | PCI                                       | 212,000         | Discharge (20th day) |
| #5      | Male, 48         | Diabetes               | Chest pain              | Electrical storm | 25 min            | 30%               | Unknown        | Yes               | Inotrope and vasopressor                  | unknown         | Death before PCI     |

VF, ventricular fibrillation; LVEF, left ventricle ejection fraction; TnI, troponin I; PCI, percutaneous coronary intervention; LMCA, left main coronary artery; RCA, right coronary artery; LAD, left anterior descending. Other abbreviations as in Table 1.

medical presentation. Moreover, the TW pattern may be missed in case of late presentation, as experimental [11,12] and clinical [13] studies suggested that its ECG features may be transient. To this regard, in our study the first ECG was acquired within few minutes from symptoms onset in all patients with TW, compared with approximately two hours after in other patients, a factor which accounted for the higher estimated prevalence of the TW pattern among the subset of patients with an early presentation (within 60 min). However, the finding that the ECG pattern remained unchanged in later ECG recordings obtained in-hospital suggests that other factors, such as the high out-of-hospital mortality rate associated with the TW pattern, may have led to the absence of this ECG pattern among STEMI patients with later presentation.

### Clinical meaning

The down-sloping ST-segment was first described in a young sudden cardiac death victim, due to cardiac asystole, presenting an ECG pattern which was interpreted as an atypical Brugada syndrome [14,15]. Subsequent studies reported that this ECG pattern may occur in patients with AMI, often complicated by VF [16].

Sclarovsky and Birnbaum [17] classified three different STEMI ECG patterns, in relation to the increased grade of myocardial ischemia: tall symmetrical T waves without ST-segment elevation (grade I); ST-segment elevation with tall T waves, without terminal QRS distortion (grade II); ST-segment elevation with positive T waves and distortion of the terminal portion of the QRS with disappearance of S wave (grade III). Patients presenting with grade III ischemia typically showed rapid progression of myocardial necrosis, larger final infarct size, lower amount of myocardial salvage by revascularization and higher incidence of re-infarction, heart failure and acute mortality compared with patients presenting with grade I or II [18], despite similar success in restoration of epicardial coronary flow, by either thrombolytic therapy or primary PCI [19].

The results of the present study indicate that the TW pattern, which may be considered an extreme grade of Sclarovsky and Birnbaum grade III ECG pattern, predicts an adverse prognosis due to both electrical and hemodynamic instability. In our study, four of five patients with TW pattern developed acute cardiogenic shock and two died. The hemodynamic deterioration with severe impairment of LV systolic function was caused by a critical amount of ischemic myocardium, as a result of acute occlusion/subocclusion of the proximal left or right coronary artery in the absence of collateral coronary circulation (no history of pre-infarct angina). Of note, the TW pattern was demonstrated in two of four (50%) patients with STEMI due to occlusion of the LM coronary artery. In this context, the occurrence of VF should be interpreted as a consequence of both acute myocardial ischemia and heart failure.

According to our findings, the TW pattern should prompt for more aggressive management strategies in the setting of an intensive care unit equipped with ventricular assist devices for mechanical support of circulation, the only way

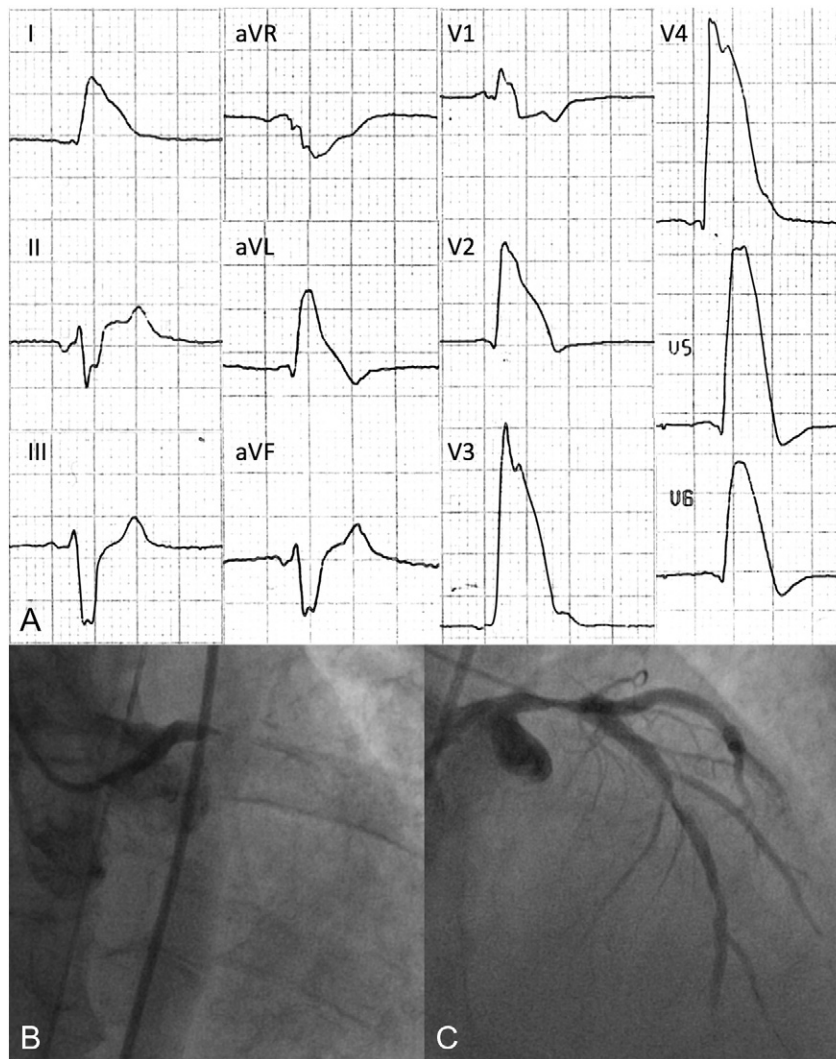


Fig. 2. A 64-year-old smoker male presented to the emergency department of a spoke hospital because of chest pain which started 30 min before and severe hypotension. The ECG performed on arrival revealed a huge triangular QRS-ST-T waveform in the anterolateral leads (Panel A). During the 30 min transfer to our hub hospital, he developed 3 episodes of ventricular fibrillation, that required multiple defibrillations. At admission, the patient was conscious, BP 80/40 mm Hg, neurologic examination was normal and ion concentrations on arterial blood gas test resulted within normal limits. Coronary angiography performed 60 min after presentation revealed a sub-occlusive lesion of the distal left main, with *Thrombolysis In Myocardial Infarction* (TIMI) 1 flow (Panel B). Multiple percutaneous transluminal coronary angioplasties were performed, with restoration of TIMI 3 flow on left anterior descending and left circumflex arteries (Panel C). Nevertheless, the hemodynamic status did not improve, so that an intra-aortic balloon pump and extracorporeal membrane oxygenator were positioned. Unfortunately, the patient died because of intracerebral haemorrhage few days later.

to treat the impending cardiogenic shock and improve survival.

#### Possible pathophysiological basis

The electrogenesis of the TW pattern in patients with AMI remains to be elucidated. Similar “triangular” ECG morphologies were demonstrated in experimental models after ligation of a large coronary artery in the dog [11] and in arterially perfused canine ventricular wedge preparations [20]. Mechanisms producing the increase in amplitude of R waves were related to the abrupt total deprivation of blood flow in large areas of myocardium, similarly to that observed in all our patients, and in cases of variant angina [11], and may be secondary to the expansion of left ventricular cavity during AMI (Brody’s hypothesis) [21], the increase in tissue resistance that affects the myocardial conductivity factor

(“the solid angle theorem”) [22], or the difference in response of endocardial and epicardial action potentials to cellular ischemia, due to differences in  $I_{to}$ ,  $I_{K,ATP}$  and early  $I_{Na}$  activity and availability [23,24]. We can also speculate that the TW pattern is the expression of the dramatic slowing of transmural electrical conduction, due to biochemical and ion concentration changes (potassium loss, fall in pH, calcium overload and sodium channels inactivation), occurring during acute myocardial ischemia [20,25–28]. This transmural electrophysiological inhomogeneity may be the basis for the “triangular” configuration that resembles J-waves of Brugada syndrome, a genetically-determined ion channel disease predisposing to VF. The diffuse dispersion of excitability, conduction and refractoriness underlying the TW pattern 1) predisposes to VF induction due to an R-on-T phenomenon as a result of a phase-2 re-entry, similar to that occurring in Brugada syndrome [20,29,30], and 2) represents

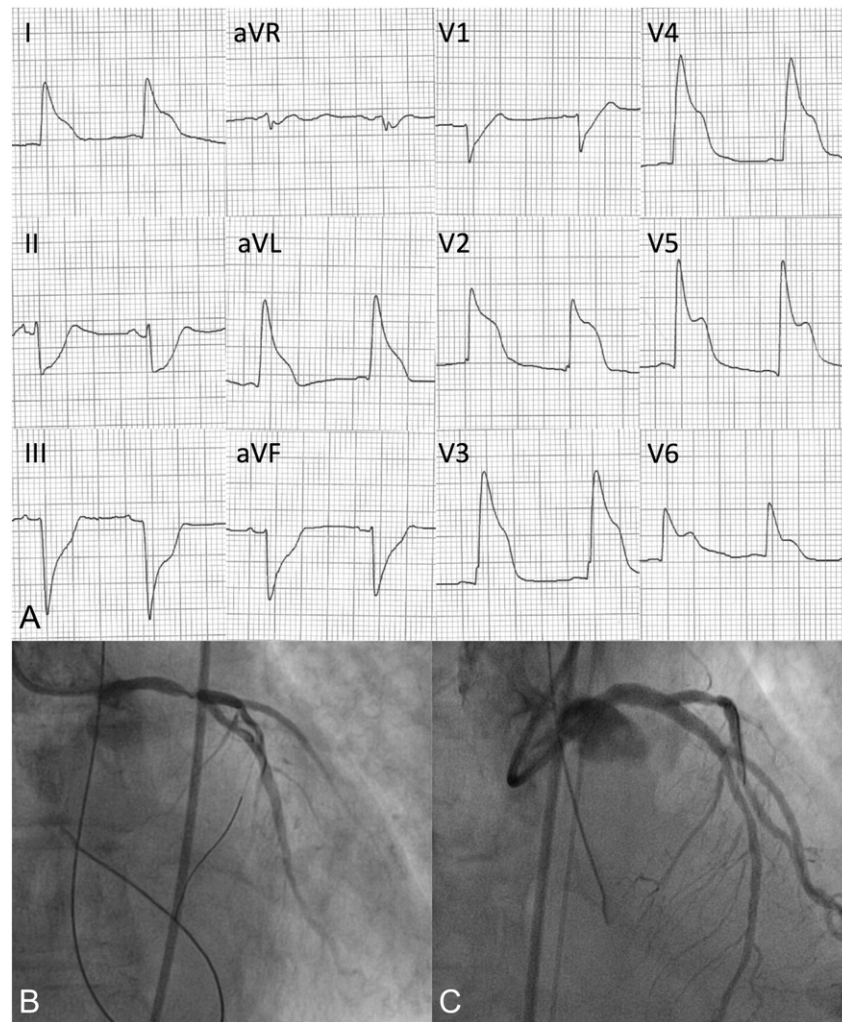


Fig. 3. A 60-year-old hypertensive female complained of sudden and severe chest pain associated with hypotension and dizziness, while attending cardiological evaluation as outpatient. An ECG was immediately recorded (Panel A), showing a prominent triangular QRS-ST-T waveform pattern in the anterolateral leads, with specular modifications in inferior leads. Coronary angiography performed 20 min later showed an occlusive thrombotic lesion of the left main, with *Thrombolysis In Myocardial Infarction* (TIMI) 0 flow (Panel B and C), effectively treated by percutaneous coronary revascularization, yet complicated by several polymorphic ventricular tachyarrhythmia and cardiogenic shock, eventually requiring intra-aortic balloon pump and extracorporeal membrane oxygenator (ECMO). During the following hospitalization, the patient did not experience major complications; the hemodynamic status progressively improves, so that the ECMO could be removed after 6 days. The patient survived and after 25 days was discharged.

the electrical manifestation of the severe myocardial ischemia which leads to mechanical paralysis of LV myocardium and cardiogenic shock.

## Conclusions

In conclusion, the present study indicates that the “triangular QRS-ST-T” waveform is an uncommon ECG pattern of STEMI, which identifies a subset of patients at high risk of both VF and cardiogenic shock accounting for high in-hospital mortality. When present, this ECG pattern should prompt aggressive management strategy including mechanical circulatory support.

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