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# High-risk ECG patterns in ST elevation myocardial infarction for mortality prediction

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ABSTRACT

*Aim:* We explored the pre-intervention (first medical contact) electrocardiographic (ECG) patterns and their relation to survival among patients with acute myocardial infarction, who presented either with ST elevation (ST elevation myocardial infarction, STEMI) or LBBB, and who underwent emergent coronary angiography in a region with a 24/7/365 STEMI network.

*Methods:* This is a retrospective analysis of 1363 consecutive patients hospitalized for first STEMI between the years 2014 and 2018. We assessed the prognostic significance of a variety of ECG categories, including location of ST elevation, severity of ischemia, intraventricular and atrioventricular conduction disorders, atrial fibrillation or flutter, junctional rhythms, heart rate, left ventricular hypertrophy and Q waves. The primary outcome was all-cause mortality between January 2014 and the end of 2020.

*Results:* The mean age of the patients was 67.9 (SD 12.8) years. The majority were treated by percutaneous coronary intervention (93.8%, $n = 1278$). Median follow-up time was 3.7 years (IQR 2.5–5.1 years) during which 22.5% ($n = 307$) of the patients died. According to Cox regression analysis, adjusted for pre-existing conditions and age, the ECG variables with statistically significant association with survival were elevated heart rate (>100 bpm) (HR 2.34, 95% CI 1.75–3.12), atrial fibrillation or flutter (HR 1.94, 95% CI 1.41–2.67), left bundle branch block (LBBB) (HR 2.62, 95% CI 1.49–4.63) and non-specific intraventricular conduction delay (NIVCD) (HR 1.85, 95% CI 1.22–2.89).

*Conclusion:* Higher heart rate, atrial fibrillation or flutter, LBBB and NIVCD are associated with worse outcome in all-comers with STEMI. Ischemia severity was not associated with impaired prognosis.

## Introduction

The treatment of ST elevation infarction (STEMI) changed dramatically when percutaneous coronary intervention (PCI) replaced thrombolysis as the preferred reperfusion therapy. Nonetheless, the mortality rates in STEMI remain high with 30-day mortality rates of 7.4–11.4% and 1-year mortality rates of 13.7–14% [1,2]. Besides the high overall mortality, STEMI patients suffer from potentially preventable life-threatening or debilitating complications, such as sudden cardiac death due to arrhythmias, conduction disorders, heart failure and mechanical complications [3–8]. Extending electrocardiographic (ECG) interpretation beyond analysis of acute ST-T changes has an important role in the recognition of patients with higher risk for mortality and complications, which is important for enhanced prognostic assessment in acute myocardial infarction.

Many ECG characteristics, such as elevated heart rate, atrial

*Abbreviations:* ECG, Electrocardiogram; STEMI, ST elevation myocardial infarction; PCI, Percutaneus coronary intervention; LBBB, Left bundle branch block; RBBB, Right bundle branch block; BBB, Bundle branch block; NIVCD, Non-pecific intraventricular conduction delay; G2I, Grade 2 ischemia; G3I, Grade 3 ischemia; LAD, Left anterior descending; LCX, Left circumflex; RCA, Right coronary artery; CABG, Coronary artery bypass grafting; PIS, Preinfarct syndrome; EMI, Evolving myocardial infarction; LVH, Left ventricular hypertrophy.

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fibrillation, other arrhythmias/dysrhythmias and conduction disorders, have been studied and proven to be independent risk factors in STEMI [9,10]. Bundle branch blocks have been linked with higher risk of mortality and morbidity, including cardiogenic shock and heart failure [8,12,13]. Pathologic Q waves and negative T waves have also been associated with worse outcome in STEMI [2,14]. In the Sclarovsky-Birnbaum ischemia grading system, grade 2 ischemia (G2I) is defined as ST elevation without QRS distortion, whereas Grade 3 ischemia (G3I) is defined as ST elevation with distortion of the terminal portion of the QRS complex. In STEMI patients, grade 3 ischemia has been associated with higher mortality rates [1,15].

The standard ECG has retained its value as the most important diagnostic laboratory method and risk marker in the acute stage of STEMI. The ECG is non-invasive, cheap and universally available, and most of the ECG changes induced by acute STEMI are relatively easy to detect. The purpose of this study was to explore (and possibly replicate) the prognostic value of different ECG markers, measured at first medical contact, in all-comers with acute myocardial infarction, who presented either with ST elevation (STEMI) or LBBB, and who underwent emergent coronary angiography in the modern era of primary PCI.

## Material and methods

### *Data collection*

This study is a part of the large MADDEC (Mass data in detection and prevention of serious adverse events in cardiovascular disease) registry study aimed to improve risk prediction of cardiac patients [17]. The MADDEC registry comprises high-quality phenotype data that can be used for accurate risk prediction among acute coronary syndrome patients [18]. Of 1509 patients with acute myocardial infarction, we included 1363 patients (flowchart in Fig. 1), who presented either with ST elevation (STEMI) or LBBB, and who were admitted to the Tampere University Heart Hospital, Finland, for primary PCI in 2014–2018. The ECG analysis was based on the first ECG that showed STEMI or LBBB taken before the patient was brought to the catheterization laboratory and diagnosed with STEMI. In 64.5% (879) of the cases the ECG was taken by ambulance personnel. Data regarding baseline characteristics, treatment and survival of STEMI patients were retrieved from hospital electronic health registry data (KARDIO registry: prospectively collected by treating physicians that includes data regarding patient characteristics, procedures, complications, and other variables) and from written patient records.

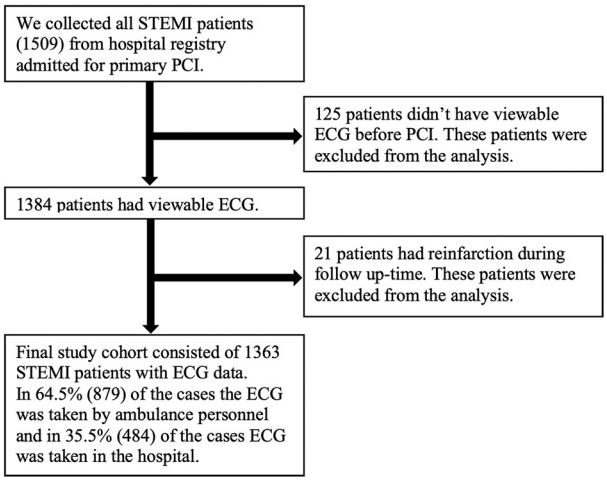


**Fig. 1.** Flowchart of data collection.

### *ECG recording and analysis*

The ECG analyses were done manually by one investigator (RL). In case of doubt, other investigators were consulted. 12- or 15-lead-ECGs were recorded during the first medical contact. For STEMI diagnosis, a guideline-based cut-point of 0.1 mV in two or more adjacent leads was used for all other leads except for leads V2 and V3, where a cut-point of 0.2 mV for male and 0.15 mV for female was used. For the additional leads V7-V9, we used a cut-point of 0.05 mV in at least two leads [19]. The sites of ST elevations were classified as follows: Antero-apical (V1-V4 [V5]); Anteroseptal (V1-V4 and V5, V6, I, aVL) (ST elevation in ≥2 lateral and ≥ 2 anterior leads or V4); Inferior (II, III, aVF); Inferolateral (II, III, aVF and V5, V6, I, aVL) (ST elevation in ≥2 inferior and ≥ 2 lateral leads); Antero-inferior (antero-apical infarct by large apical recurrent artery) (V1-V4 [V5] and II, III, aVF) (ST elevation in ≥2 anterior and ≥ 2 inferior leads); Lateral (I, aVL, V5, V6); and infero-basal (previously named as posterior) (V7-V9). For statistical purposes, the antero-apical and anteroseptal infarct locations were combined, and this was also the case for inferior and inferolateral location. If both lateral and infero-basal ST elevation was present simultaneously, the location of ST elevation was recorded as infero-basal as in most cases the predominant ST elevations were only seen in V7-V9. Diagnosis of acute MI in patients with pacemaker rhythm or LBBB was based on symptoms, troponin values and emergent coronary angiography findings. The ST elevation locations of these patients were not recorded.

We also included culprit vessels shown in the angiography corresponding to different ST elevation locations. We classified culprit vessels for 4 locations: LAD area (left anterior descending with its diagonal branches), LCX area (left circumflex with obtuse marginal branches and intermediary branch), RCA area (right coronary artery with its posterior descending and posterolateral branch) and left main.

Rhythm was classified as sinus rhythm, atrial fibrillation/flutter, second- or third-degree AV block, junctional rhythm, or other rhythm (supraventricular tachycardia, ectopic rhythm, ventricular tachycardia, or pacemaker rhythm). We also recorded first-degree AV block when the PQ interval was >200 ms. Heart rate was measured from the ECG. We used a cut-point of >100 bpm for tachycardia and < 40 bpm for bradycardia.

Q waves were considered pathological in leads V2 and V3 when the Q wave width was >20 ms. In the other leads, we used a cut-off >30 ms and 0.1 mV, when associated with significant ST elevation. Q waves in the leads aVR, III and V1 were not recorded. The cut-off for inverted T waves was ≥0.05 mV, in at least one lead with significant ST elevation. T waves in the leads aVR, III and V1 were not recorded. Patients with broad QRS (≥120 ms), neither pathological Q waves nor inverted T waves were recorded [2].

For the classification of temporal evolution of the infarct process, we used the previously published concepts of Preinfarction syndrome (PIS) and evolving myocardial infarction (EMI) [2,20]. Based on this classification, PIS was defined as ST segment elevation with a positive T wave and without pathological Q waves. EMI was defined as ST segment elevation accompanied with pathological Q waves and/or T wave inversion. If QRS ≥120 ms dynamic changes were not determined [2,20].

For the grade of ischemia, we used previously published definitions, based on the QRS complex. In leads with an rS-type QRS morphology (usually V1-V2/V3) disappearing of the S wave was considered as G3I. In leads with the qR-type QRS morphology (usually inferior, lateral and posterior leads) J-point elevation ≥50% of the height of the R wave was considered as G3I. In G2I, there was significant ST elevation, but no changes in the QRS complex. If the QRS duration as ≥120 ms or if T wave inversion was present, ischemia grade was not determined [1,15].

In case of broad QRS (≥120 ms) not caused by ventricular pacing we used the Minnesota code classification system for the ECG diagnoses left bundle branch block (LBBB), right bundle branch block (RBBB) and NIVCD [21]. Left ventricular hypertrophy (LVH) was defined according

to the Sokolow-Lyon criteria (the sum of the S wave in lead V1 and R wave in lead V5 or V6 ≥ 3.5 mV) or based on the criterion R wave amplitude in aVL ≥1.1 mV [22].

### *Statistical analyses*

The prevalence of baseline characteristics and ECG categories are reported in absolute numbers and by proportional numbers (percentages). The association of ECG categories with survival were analyzed with both age and disease adjusted (previous myocardial infarction, dyslipidemia, hypertension, any type of diabetes, valvular heart diseases, peripheral artery disease, serum creatinine) Cox regression accepting only statistically significant variables in the analysis for reducing the complexity of the models. Statistical analyses were done with SPSS statistics (version 27.0). A *p*-value of 0.05 or less was considered statistically significant.

## Results

Table 1 shows the characteristics of the patient population, including the chosen reperfusion therapy. The mean age was 67.9 years and 70.4% of the population were men. The majority of the population were treated by PCI (93.4%), and only 3.3% of the population were not treated invasively. In invasively treated patient, median time from treatment decision (reperfusion therapy) to first balloon dilatation was 77.0 min (interquartile range [IQR] 61.0–100.0). The median follow-up time was 3.7 years (IQR 2.5–5.1). During follow-up, 307 (22.5%) patients died, 210 (15.4%) patients died to cardiovascular causes.

The most common ST elevation locations were antero-apical/anteroseptal (45.9%) and inferior/inferolateral (41.0%). Predominantly infero-basal (or posterior) ST elevations accounted for only 1.8% of the cases. The majority of the patients were in sinus rhythm (85.2%) and 9.7% were in atrial fibrillation or flutter. Bundle branch blocks or NIVCD was present in 12.3%, and LVH in 7.9% of the patients. Regarding the dynamic ECG classification, the EMI pattern was present in 27.8%, while according to the ischemia grading system, G3I was found in 13.4% of the patients. Table 2 shows the incidence of the different ECG categories in the entire patient population.

Culprit vessels for each ST elevation location and LBBB are presented in Table 3. In antero-apical/anteroseptal infarct most frequent culprit vessel location was LAD area (87.0%, 544). In inferior/inferolateral infarct most frequents culprit vessel locations were RCA area (74.4%, 416) and LCX area (17.2%, 96). In lateral infarct most frequent culprit vessel locations were LAD area (50.0%, 45) and LCX area (30.3%, 27).

### *The association between ECG categories and mortality*

In Cox-regression analysis adjusted for age, significant risk factors for mortality were elevated heart rate (Hazard Ratio [HR] 2.24, 95% CI 1.70–2.95), atrial fibrillation or flutter (HR 1.91, 95% CI 1.40–2.60), LBBB (HR 2.49, 95% CI 1.43–4.36) and NIVCD (HR 2.34, 95% CI 1.57–3.49). When all these factors were entered into the same regression model, all the ECG categories remained as significant risk predictors: elevated heart rate (HR 2.02, 95% CI 1.52–2.70), atrial fibrillation or flutter (HR 1.69, 95% CI 1.24–2.31), LBBB (HR 2.06, 95% CI 1.17–3.63) and NIVCD (HR 2.30, 95% CI 1.54–3.44). After adjustment for age and prevalent cardiovascular comorbidities (previous myocardial infarction, dyslipidemia, hypertension, any type of diabetes, valvular heart diseases, peripheral artery disease and serum creatinine), the same ECG patterns remained significant predictors for mortality: elevated heart rate (HR 2.34, 95% CI 1.75–3.12), atrial fibrillation or flutter (HR 1.94, 95% CI 1.41–2.67), LBBB (HR 2.62, 95% CI 1.49–4.63) and NIVCD (HR 1.85, 95% CI 1.22–2.81; Table 4). Effect of broad QRS to survival is demonstrated in Kaplan-Meier estimate (Fig. 2).

Compared with other sites of ST elevations, inferior/inferolateral infarct was associated with better prognosis in univariate analysis, but not after adjusting for clinical factors. Other ST elevation locations did not show any significant association with outcome (Table 4). RBBB and

**Table 1**
Baseline characteristics and mode of reperfusion therapy of 1363 consecutive patients undergoing coronary angiography for STEMI 2014–2018.

| | Percentage (n) |
|---|---|
| Mean age (SD) | 67.9 (12.8) |
| Mean BMI kg/m2[a] (SD) | 27.6 (5.1) |
| Men | 70.4 (959) |
| Smoker (previous or active)[a] | 49,7 (574) |
| Previous myocardial infarction | 16.2 (220) |
| Previous PCI | 13.4 (182) |
| Previous CABG | 4.5 (62) |
| Hypertension | 54.3 (715) |
| Dyslipidemia | 47.0 (607) |
| History of atrial fibrillation | 13.5 (166) |
| Valvular heart disease | 3.8 (52) |
| Diabetes | 21.9 (291) |
| Peripheral artery disease | 5.2 (70) |
| Treated or active cancer (any type) | 8.1 (100) |
| Dementia[a] | 2.5 (24) |
| Mean creatinine, μmol/l (SD) | 86.3 (45.1) |
| Median time from pain onset to first ECG, minutes (IQR)[a] | 101.0 (48.0–232.3) |
| Median time from treatment decision to balloon dilatation, (IQR)[a] | 77.0 (61.0–100.0) |
| PCI | 93.8 (1278) |
| CABG | 1.9 (26) |
| PCI and CABG | 1.0 (13) |

Abbreviations: SD = standard deviation, BMI = body mass index; PCI = percutaneous coronary intervention; CABG = coronary artery bypass grafting; IQR, interquartile range.

[a] Under 90% of valid cases: Smoking ($n = 1156$) Height ($n = 1150$), weight ($n = 1209$), BMI ($n = 1146$), dementia ($n = 967$), pain to ECG in minutes ($n = 1222$), treatment decision to first expansion in minutes ($n = 1132$).

**Table 2**
ST elevation locations and ECG charasteristics of 1363 STEMI patients.

| | Percentage (n) | | Percentage (n) |
|---|---|---|---|
| ST elevation location (not available in 2.2%, $n = 31$) | | QRS changes | |
| Antero-apical/ Anteroseptal | 45.9 (625) | No QRS changes (<120 ms) | 87.7 (1195) |
| Inferior/inferolateral | 41.0 (559) | LBBB | 1.9 (26) |
| Anterior and inferior | 2.3 (32) | RBBB | 5.5 (75) |
| Lateral | 6.5 (89) | NIVCD | 4.9 (67) |
| Infero-basal | 1.8 (25) | | |
| | | LVH | 7.9 (107) |
| Heart rate (beats/min) | | | |
| 40–100 | 84.7 (1155) | Dynamic changes | |
| <40 | 2.0 (27) | Pathologic Q wave | 21.7 (296) |
| >100 | 13.2 (180) | PIS (only ST elevation) | 59,6 (810) |
| | | EMI, no reperfusion | 18,2 (248) |
| Rhythm status | | EMI, partial reperfusion (negative T wave) | 9,6 (131) |
| Sinus rhythm | 85.2 (1159) | | |
| Atrial fibrillation or flutter | 9.7 (132) | Grade 2 ischemia | 63.4 (864) |
| First-degree AV block | 15.9 (216) | Grade 3 ischemia | 13.4 (182) |
| Second- or third-degree AV block | 2.2 (30) | | |
| Junctional rhythm | 1.8 (24) | | |
| Other (ectopic, SVT, VT) | 1.1 (15) | | |

Abbreviations: SVT = supraventricular tachycardia, VT = ventricular tachycardia, LBBB = left bundle branch block, RBBB = right bundle branch block, NIVCD = nonspecific intraventricular conduction delay, LVH = left ventricular hypertrophy, PIS = preinfarct syndrome, EMI = evolving myocardial infarction.

**Table 3**
Culprit vessels for ST elevation locations.

| ST elevation location (n) | LAD area percentage (n) | LCX area | RCA area | Left Main | No data |
|---|---|---|---|---|---|
| Antero-apical/ anteroseptal (625) | 87.0 (544) | 1.9 (12) | 2.1 (13) | 1.3 (8) | 7.7 (48) |
| Inferior/inferolateral (559) | 2.7 (15) | 17.2 (96) | 74.4 (416) | 0.4 (2) | 5.4 (30) |
| Anteroinferior (32) | 50.0 (16) | 12.5 (4) | 31.3 (10) | 0.0 (0) | 6.3 (2) |
| Lateral (89) | 50.1 (45) | 30.3 (27) | 1.1 (1) | 1.1 (1) | 16.9 (15) |
| Infero-basal (25) | 4.0 (1) | 76.0 (19) | 4.0 (1) | 4.0 (1) | 8.0 (2) |
| LBBB (26) | 26.9 (7) | 19.2 (5) | 19.2 (5) | 7.7 (2) | 26.9 (7) |

Abbreviations: LAD = left anterior descending, LCX = left circumflex, RCA = right coronary artery, LBBB = left bundle branch block,

LVH were associated with higher mortality rates in univariate analysis, but not after adjustment for clinical risk factors. Neither pathologic Q waves nor dynamic ECG changes (PIS/EMI classification) or grade 3 ischemia were associated with impaired prognosis after controlling for confounding factors (Table 4).

When focusing the survival analysis only to cardiovascular mortality (accounting for 68.4% of all deaths), after adjusting for age and prevalent comorbidities (as described above) significant risk factors were elevated heart rate (HR 2.49, 95% CI 1.77–3.52), bradycardia (HR < 40 bpm) (HR 1.98, 95% CI 1.00–3.91), atrial fibrillation or flutter (HR 1.67, 95% CI 1.11–2.49), LBBB (HR 2.85, 95% CI 1.44–5.65), RBBB (HR 1.86, 95% CI 1.19–2.89) and NIVCD (HR 2.28, 95% CI 1.42–3.66). Using similar adjustments, inferior ST elevation location was also associated with better prognosis (HR 0.74, 95% CI 0.55–0.99).

### *The association between ECG categories and patient status during admission*

The association of primary ECG findings with LVEF, decompensated heart failure (Killip classification II-IV) and need for resuscitations are presented in Table 5. Briefly, the ECG changes that were associated with mortality and CV mortality were almost all also associated with worse clinical condition during subsequent hospital admission as depicted by lower LVEF, higher prevalence of decompensated heart failure and higher rates of resuscitations. When the analysis of the association between ECG categories and overall mortality was repeated by adjusting with age and the presence of decompensated heart failure (HR 2.89, 95% CI 2.27–3.69) and the need of resuscitations (HR 3.92, 2.98–5.17), NIVCD (HR 1.69, 95% CI 1.11–2.51) and atrial fibrillation (HR 1.63, 95% CI 1.20–2.22) remained as significant risk factors for mortality despite of their clear link with these adjusting variables depicting poor immediate clinical outcome. The association between mortality and RBBB (1.23 95% CI 0.83–1.83), LBBB (1.70, 95% CI 0.96–3.03) and elevated heart rate (1.30, 95% CI 0.96–1.75), were not statistically significant after adjusting with these factors. LVEF was omitted from the model due to large number of missing data (73.7% of data available).

## Discussion

The main finding of this study was that several ECG categories in the presenting ECG were associated with worse clinical outcome in patients with acute STEMI, of which the vast majority were treated by primary PCI. LBBB, NIVCD, atrial fibrillation or flutter, and elevated heart rate

**Table 4**
Hazard risks and adjusted hazard risks corresponding to specific ECG patterns. Four patients had pacemaker rhythm and were excluded from the analysis.

| | HR (95% CI) | p-value | Age adjusted HR (95% CI) | p-value | Age and disease[a] adjusted HR (95% CI) | *p*-value |
|---|---|---|---|---|---|---|
| ST elevation location (not available in 2.2%, n = 31)[b] | | | | | | |
| Antero-apical/anteroseptal | 1.08 (0.86–1.35) | 0.51 | 1.13 (0.90–1.42) | 0.29 | 1.14 (0.90–1.44) | 0.27 |
| Inferior/inferolateral | 0.78 (0.62–0.99) | 0.040 | 0.82 (0.65–1.03) | 0.088 | 0.82 (0.64–1.05) | 0.11 |
| Anterior and inferior | 1.43 (0.76–2.69) | 0.26 | 0.93 (0.49–1.75) | 0.82 | 0.89 (0.47–1.69) | 0.72 |
| Lateral | 0.91 (0.56–1.46) | 0.69 | 0.91 (0.56–1.46) | 0.69 | 0.92 (0.56–1.53) | 0.76 |
| Infero-basal | 1.43 (0.71–2.88) | 0.32 | 1.10 (0.55–2.23) | 0.79 | 0.87 (0.41–1.86) | 0.72 |
| Heart rate (beats/min) | | | | | | |
| 40–100 | REFERENCE | | REFERENCE | | REFERENCE | |
| <40 | 2.11 (1.15–3.87) | 0.015 | 1.33 (0.73–2.44) | 0.36 | 1.50 (0.82–2.78) | 0.19 |
| >100 | 2.18 (1.66–2.87) | <0.001 | 2.24 (1.70–2.95) | <0.001 | 2.34 (1.75–3.12) | <0.001 |
| Rhythm status | | | | | | |
| Sinus rhythm | REFERENCE | | REFERENCE | | REFERENCE | |
| Atrial fibrillation or flutter | 3.42 (2.54–4.61) | <0,001 | 1.91 (1.40–2.60) | <0.001 | 1.94 (1.41–2.67) | <0.001 |
| First-degree AV block | 1.92 (1.43–2.56) | <0,001 | 1.30 (0.97–1.74) | 0.079 | 1.10 (0.80–1.50) | 0.56 |
| Second- or third-degree AV block | 3.14 (1.82–5.42) | <0.001 | 1.62 (0.93–2.83) | 0.089 | 1.74 (0.99–3.04) | 0.054 |
| Junctional rhythm | 1.46 (0.64–3.29) | 0.37 | 1.11 (0.49–2.51) | 0.81 | 1.03 (0.42–2.51) | 0.95 |
| Other (ectopic, SVT, VT) | 2.00 (0.74–5.40) | 0.17 | 2.18 (0.81–5.88) | 0.13 | 2.10 (0.55–5.51) | 0.35 |
| QRS-changes | | | | | | |
| QRS < 120 ms | REFERENCE | | REFERENCE | | REFERENCE | |
| LBBB | 3.18 (1.82–5.56) | <0,001 | 2.49 (1.43–4.36) | 0.002 | 2.62 (1.49–4.63) | 0.001 |
| RBBB | 2.18 (1.48–3.21) | <0,001 | 1.38 (0.93–2.03) | 0.11 | 1.40 (0.94–2.09) | 0.10 |
| NIVCD | 2.57 (1.72–3.82) | <0,001 | 2.34 (1.57–3.49) | <0.001 | 1.85 (1.22–2.81) | 0.004 |
| LVH vs no LVH | 1.46 (1.08–2.10) | 0.040 | 1.26 (0.88–1.81) | 0.21 | 1.15 (0.79–1.67) | 0.45 |
| Dynamic changes | | | | | | |
| Pathologic Q wave vs no Q wave | 1.22 (0.92–1.63) | 0.17 | 1.29 (0.97–1.72) | 0.078 | 1.17 (0.86–1.58) | 0.32 |
| PIS | REFERENCE | | REFERENCE | | REFERENCE | |
| EMI, no reperfusion | 1.17 (0.67–1.60) | 0.32 | 1.19 (0.87–1.62) | 0.28 | 1.16 (0.84–1.60) | 0.38 |
| EMI, partial reperfusion | 1.03 (0.67–1.57) | 0.90 | 0.93 (0.61–1.41) | 0.72 | 0.90 (0.57–1.42) | 0.65 |
| Grade 2 ischemia | REFERENCE | | REFERENCE | | REFERENCE | |
| Grade 3 ischemia | 0.79 (0.53–1.16) | 0.23 | 0.97 (0.65–1.44) | 0.88 | 0.87 (0.56–1.34) | 0.52 |

Abbreviations: HR = Hazard ratio, CI = confidence interval, SVT = supraventricular tachycardia, VT = ventricular tachycardia, LBBB = left bundle branch block, RBBB = right bundle branch block, NIVCD = nonspecific intraventricular conduction delay, LVH = left ventricular hypertrophy, PIS = preinfarct syndrome, EMI = evolving myocardial infarction.

[a] Adjusted diseased consist of previous myocardial infarction, dyslipidemia, hypertension, any type of diabetes, valvular heart diseases, peripheral artery disease, serum creatinine.

[b] HR values for ST elevation locations is evaluated by referencing to all other ST elevation locations.

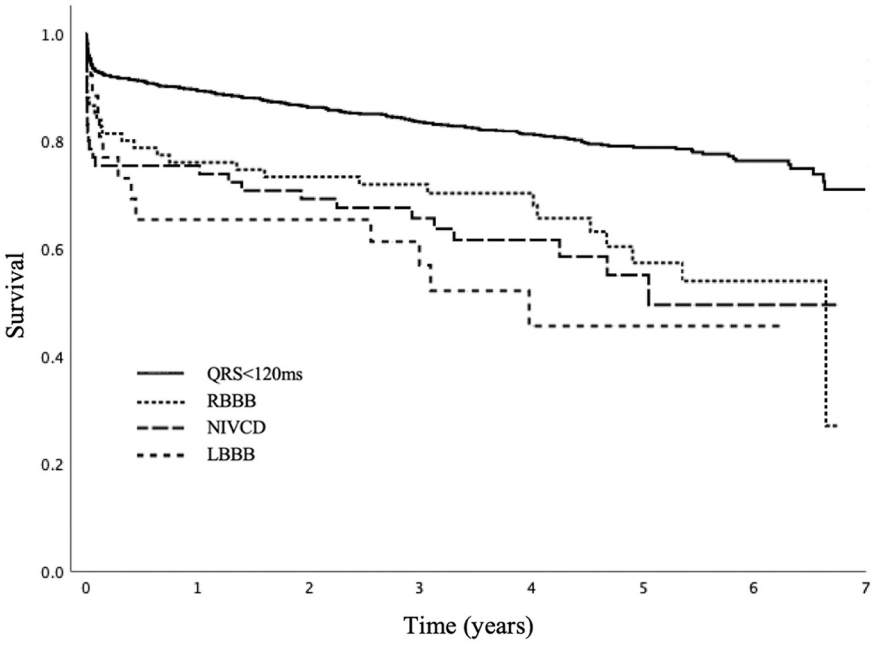


**Fig. 2.** Kaplan-meier estimate of survival among STEMI patients classified by QRS complex.

**Table 5**
The association between primary ECG findings and subsequent patient status and the need of resuscitations during treatment for STEMI.

| | LVEF | p-value | Decompensated heart failure[a] | | Resuscitation during treatment[b] | |
|---|---|---|---|---|---|---|
| ST elevation location (not available in 2.2%, n = 31) | | <0.001 | | <0.001 | | 0.590 |
| Antero-apical/anteroseptal | 44.1 (11.6) | | 20.0% (124) | | 13.6% (85) | |
| Inferior/inferolateral | 51.1 (9.3) | | 11.5% (64) | | 11.5% (64) | |
| Anterior and inferior | 46.5 (10.8) | | 12.5% (4) | | 9.4% (3) | |
| Lateral | 50.0 (11.3) | | 23.3% (21) | | 13.3% (12) | |
| Infero-basal | 47.2 (12.0) | | 24% (6) | | 20% (5) | |
| Heart rate (beats/min) | | <0.001 | | <0.001 | | <0.001 |
| 40–100 | 48.0 (10.9) | | 13.8% (159) | | 10.4% (120) | |
| <40 | 49.3 (11.1) | | 18.5% (5) | | 11.1% (3) | |
| >100 | 42.2 (12.3) | | 40.4% (72) | | 28.5% (51) | |
| Rhythm status | | 0.288 | | 0.023 | | 0.002 |
| Sinus rhythm | 47.2 (11.1) | | 15.3% (144) | | 10.8% (102) | |
| Atrial fibrillation or flutter | 44.9 (12.8) | | 26.5% (35) | | 22.7% (30) | |
| First degree AV block | 48.4 (11.3) | | 19.1% (41) | | 14.4% (31) | |
| Second- or third-degree AV block | 48.0 (11.5) | | 26.7% (8) | | 23.3% (7) | |
| Junctional rhythm | 47.7 (8.0) | | 20.8% (5) | | 8.3% (2) | |
| Other (ectopic, SVT, VT) | 48.3 (10.3) | | 21.4% (3) | | 14.3% (2) | |
| QRS-changes | | <0.001 | | <0.001 | | <0.001 |
| No QRS changes (<120 ms) | 47.9 (10.8) | | 15.5% (184) | | 11.1% (132) | |
| LBBB | 34.6 (9.3) | | 50% (13) | | 15.4% (22) | |
| RBBB | 47.6 (14.4) | | 26.7% (20) | | 25.3% (19) | |
| NIVCD | 40.1 (10.7) | | 29.2% (19) | | 29.2% (19) | |

[a] Killip Classes II-IV.
[b] Defibrillation and/or chest compressions due to hemodynamically unstable ventricular tachycardia, ventricular fibrillation, or bradycardia.

(100 bpm) in the pre-procedural ECG were independently associated with over two-fold higher mortality rates. Compared with other locations, inferior or inferolateral ST elevations was associated with lower and RBBB was associated with higher cardiovascular mortality. Interestingly, grade of ischemia was not associated with higher mortality.

Our retrospective study highlights the importance of extended ECG analysis, beyond "simple" recording of ST changes, for improved individual risk assessment in STEMI patients. Historically, the mortality of patients with acute myocardial infarction and LBBB reached 40% in the thrombolytic era [23]. In patients with acute MI, who underwent coronary angiography, Widimsky et al. reported those with LBBB presented twice as often in cardiogenic shock as patients without LBBB, and the prognosis of patients with LBBB remained poor whether the LBBB was old or presumably new [24]. Pera et al. observed similar in-hospital mortality rates, and the 1-year mortality rate was over 20% in patients with LBBB [8]. Despite the fact that RBBB (with or without ST elevation) was recently included as an indication for reperfusion therapy, when comparing to patients without broad QRS, this conduction disorder was not associated with increased overall mortality in our study, although in adjusted analysis it did associate with increased cardiovascular mortality [19].

Myocardial ischemia or infarction may also lead to prolonged QRS duration without affecting the main branches of the conduction system. In contrast to bundle branch blocks, nonspecific conduction delay — wide QRS (≥120 ms) not meeting the criteria for LBBB or RBBB — is not a well-established marker of impaired prognosis in STEMI patients. Studies from the thrombolytic era, including the GUSTO-I trial, indicated that QRS duration, but not RBBB, was associated with increased

30-mortality rates [25]. In a cohort of patients with suspected STEMI, QRS >111 ms was a predictor of short term-mortality [12]. The fact that our study found a strong association with increased all-cause mortality during more than three-year follow-up in patients with LBBB or NIVCD, highlights the importance of rigorous risk evaluation in acute MI patients with these conduction delays.

We found atrial fibrillation or flutter to be one of the most significant risk factors for mortality among STEMI patients. In addition to the risk of thromboembolic stroke, patients with atrial fibrillation also have an increased risk for other unfavorable cardiac outcomes. The study by Marijon et al. showed that in the anticoagulated AF population, 37.4% of the deaths were related to cardiac causes and 7.0% to stroke. The risk for cardiac death was three times higher among patients with heart failure and two times higher among patients with prior MI. [26] In a recent report from the TOTAL trial, patients with pre-procedural AF had a higher incidence of severe Killip class IV heart failure [27]. In study by Anttonen et al. (2021) STEMI patients with atrial fibrillation had over 50% higher adjusted mortality risk [28]. While rapid ventricular rate in atrial fibrillation may negatively influence cardiac hemodynamics and lead to worsening pump function, the risk of atrial fibrillation complicating acute myocardial infarction is considered proportional to the severity of myocardial ischemia [29]. The positive correlation between increased heart rate and mortality was also shown in the current study.

Although G3I was closely associated with severe microvascular damage on cardiac magnetic resonance imaging in a previous study by Weaver et al. (2011), neither ischemia degree nor the EMI pattern were predictors of increased all-cause mortality in our study [30]. In previous studies, patients who have terminal QRS distortion in addition to ST segment elevation (G3I) on their presenting ECG had higher mortality and larger final infarct size than patients without QRS changes [31]. However, in line with the findings from the present study, in a recent study, G3I was not associated with increased all-cause mortality, although the authors presented an association with increased cardiovascular mortality [27].

The PIS represents the window of opportunity to treat STEMI patients before the evolvement towards infarction with Q waves and or inverted T waves (EMI) and irreversible myocardial damage [20]. Even though patients with G3I exhibit a larger myocardial area at risk and probably more severe ischemia, the results of our study suggest that with the “modern” primary PCI strategy and improved anti-thrombotic therapy of STEMI patients, this excess risk does not translate into increased rates of all-cause mortality [31].

We found inferior or inferolateral infarct to predict better lower cardiovascular mortality compared with other ST elevation locations (antero-apical/anteroseptal, antero-inferior, lateral and infero-basal). Previous studies showed similar results: inferior infarct was associated with smaller infarct size, greater ejection fraction, lower in-hospital mortality and overall cardiac mortality when comparing to anterior infarcts [32]. Although our ST elevation location classification was more complex, inferior/inferolateral infarct was still associated with better outcome in the modern PCI era.

Our study provides an update of the importance of different ECG categories for risk stratification of STEMI patients. Our registry data show extremely short times from the therapeutic decision for reperfusion therapy to invasive treatment, reflecting the strength of a well-organized STEMI network with wireless ECG transmission and invasive cardiologist-based decision making. We decided to focus on several prognostic ECG categories instead of describing only separate ischemic or arrhythmic ECG changes. While our study was retrospective, the ECG investigators were totally blinded to the clinical data of the patients and the number of patients was large. In our opinion, the post hoc nature of the study should not have significant impact on the results.

As for limitations, this study is a retrospective registry study and although all consecutive patients with a pre-angiography recorded ECG were included, some patients with ST elevation infarction or with an equivalent condition with an acute coronary occlusion could be missed in the early diagnostic phase if the first medical contact fails to suspect an acute myocardial infarction for any reason and a cardiologist on call is not consulted. This could also explain the relatively small fraction (1.8%) of patients in the present study showing ST elevations mostly in leads V7-V9. These STEMI patients (showing ST elevations only in V7-V9) can be frequently missed and treated as NSTEMI patients. However, the low number of these cases is also explained by the fact that in many inferior and lateral ST elevations posterior V7-V9 lead were not recorded since significant ST elevations were already visible in other lead groupings of the standard 12-channel ECG and the decision to bring the patient immediately for revascularization was already made based on that information. Additionally, we did not record the presence of the modified Scarbossa's criteria (also known as Smiths criteria) for diagnosing STEMI equivalent condition in the presence of LBBB [26] or paced rhythm [4] that could have been used to identify the infarct location [33]. Incorporation of these diagnostic criteria to risk stratification in STEMI could be very interesting and warrants further studies.

In conclusion, LBBB and NIVCD proved to be important pre-procedural ECG patterns for the prediction of mortality in patients with acute myocardial infarction, who underwent emergent coronary angiography. In addition, atrial fibrillation or flutter was an independent predictor of outcome and resulted in a two-fold higher mortality rates in our study population. We consider these ECG categories as ‘high-risk’ ECG patterns predicting poor prognosis despite “modern” treatment of STEMI with primary PCI.

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## Declaration of Competing Interest

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