

# Atypical Electrocardiographic Presentations in Need of Primary Percutaneous Coronary Intervention



Georgios Tzimas, MD<sup>a,\*</sup>, Panagiotis Antiochos, MD<sup>a</sup>, Pierre Monney, MD<sup>a</sup>, Eric Eeckhout, MD, PhD<sup>a</sup>, David Meier, MD<sup>a</sup>, Stephane Fournier, MD<sup>a</sup>, Brahim Harbaoui, MD<sup>b</sup>, Olivier Muller, MD, PhD<sup>a</sup>, and Jürg Schläpfer, MD<sup>a</sup>

Early initiation of reperfusion therapy remains the cornerstone of successful management for ST-elevation myocardial infarction (STEMI). Rapid restoration of coronary blood flow relies on prompt recognition of the typical ST-segment elevation on a 12-lead electrocardiogram (ECG)—a surrogate for coronary occlusion or critical stenosis—allowing timely activation of the STEMI protocol cascade, with a major positive impact in mortality and clinical outcomes. However, atypical, very high risk ECG patterns—known as “STEMI equivalents”—are present in 10% to 25% of patients with ongoing myocardial ischemia in need of urgent primary percutaneous coronary intervention. Though briefly mentioned in the current recommendations, structured clinical data on those specific ECG presentations are lacking. By thoroughly searching MEDLINE and EMBASE we conducted a structured review of non-STEMI, albeit very high risk, ECG patterns of acute coronary syndrome, often associated with coronary occlusion or critical stenosis. After screening 997 studies, we identified the following distinct “STEMI equivalent” ECG patterns: Wellens’ syndrome, de Winter sign, hyperacute T waves, left bundle branch block—including paced rhythm—and right bundle branch block. For each pattern, a brief summary of the existing evidence, together with the sensitivity, specificity, and positive predictive value—whenever available—are presented. In conclusion, prompt recognition of “STEMI equivalent” ECG patterns is crucial for every physician or paramedic dealing with acute coronary syndrome patients in the emergency department or the prehospital setting, as misinterpretation of those high risk presentations can lead to reperfusion delays and worse outcomes. © 2019 Elsevier Inc. All rights reserved. (Am J Cardiol 2019;124:1305–1314)

Achieving the shortest possible time to coronary revascularization is the cornerstone of management of acute myocardial infarction (MI) with ST-segment elevation MI (STEMI). Prompt and reliable prehospital electrocardiogram (ECG) diagnosis and autonomous STEMI team activation by emergency physicians have currently evolved into crucial steps in the reperfusion strategy. Despite the absence of a classical STEMI ECG pattern, up to 10% to 25% of acute coronary syndrome (ACS) patients requiring urgent reperfusion therapy may present with atypical ECG patterns. This heterogeneous, very high risk patient population represents a significant challenge for physicians and paramedics, especially in the prehospital setting. Although the ECG will never be able to perfectly predict coronary vessel occlusion or very critical stenosis in every ACS patient, several studies as well as countless case reports highlight the lack of recognition of certain atypical, very high risk ECG patterns that may require primary percutaneous coronary intervention strategy.<sup>1</sup> Though briefly mentioned in the current recommendations, up-to-date information on those

specific “STEMI equivalent” ECG patterns as well as data on their sensitivity, specificity, and predictive value are lacking. Therefore, the aim of the current article is to provide a structured review of the most commonly reported non-ST-segment elevation ECG patterns associated with acute coronary occlusion, in the ACS patients’ population.

## Methods

We searched electronic databases (MEDLINE, EMBASE), from inception through January 2019 to identify case series, original research and review articles for “STEMI equivalents.” Additional relevant articles were identified from thoroughly searching bibliographies of retrieved articles. Research was performed according to the PRISMA statement.

The initial search string used in the article title or abstract was: [STEMI equivalent]. Thus, 6 ECG patterns were identified based on the presence of a complete angiographic occlusion of a coronary artery in the context of a non-STEMI ECG presentation. Following this first search, the following MESH terms were researched in the manuscript title/abstract: (Wellens) OR (de Winter) OR (hyperacute T waves) OR (STEMI AND left bundle branch block [LBBB]) OR (STEMI AND LBBB) OR (STEMI and paced) OR (STEMI and pacemaker) OR (STEMI and right bundle branch block [RBBB]) OR (STEMI and RBBB). All related articles cited in the studies found from the above

<sup>a</sup>Department of Cardiology, University Hospital of Lausanne, Lausanne, Switzerland; and <sup>b</sup>University Hospital la Croix-Rousse, Hospices Civils de Lyon, Lyon, France. Manuscript received February 18, 2019; revised manuscript received and accepted July 2, 2019.

See page 1313 for disclosure information.

\*Corresponding author: Tel: +41 795560629.

E-mail address: [Georgios.tzimas@chuv.ch](mailto:Georgios.tzimas@chuv.ch) (G. Tzimas).

search were also included. Exclusion criteria included non-english manuscripts, nonhuman populations, and case reports. After removal of duplicates, the titles and abstracts of all citations were independently reviewed by 2 authors (GT, PA) for potential inclusion. Next, the full text of potentially relevant citations was reviewed. In case of discordance, decision was made after consultation of a third senior author (JS).

A total of 997 articles were found in the literature search, of which 41 were found to meet the screening criteria (Figure 1). All studies that reported data from patients with ECG patterns consistent with the initial description were included. After consensus for final inclusion, data concerning

clinical and ECG presentation, sensitivity, specificity, and positive predictive value were extracted. The quality assessment of the remaining, included articles was carried out by the primary investigator (GT).

## Results

*Wellens' syndrome* is an ECG pattern characterized by 2 types of electrocardiographic T-wave changes, in patients presenting with suspicion of ACS.<sup>2</sup> Type 1 is defined by symmetric deeply inverted T waves in leads V2 and V3, whereas type 2 is defined by biphasic T waves in leads V2 and V3 (Figure 2). Although leads V2 and V3 are the

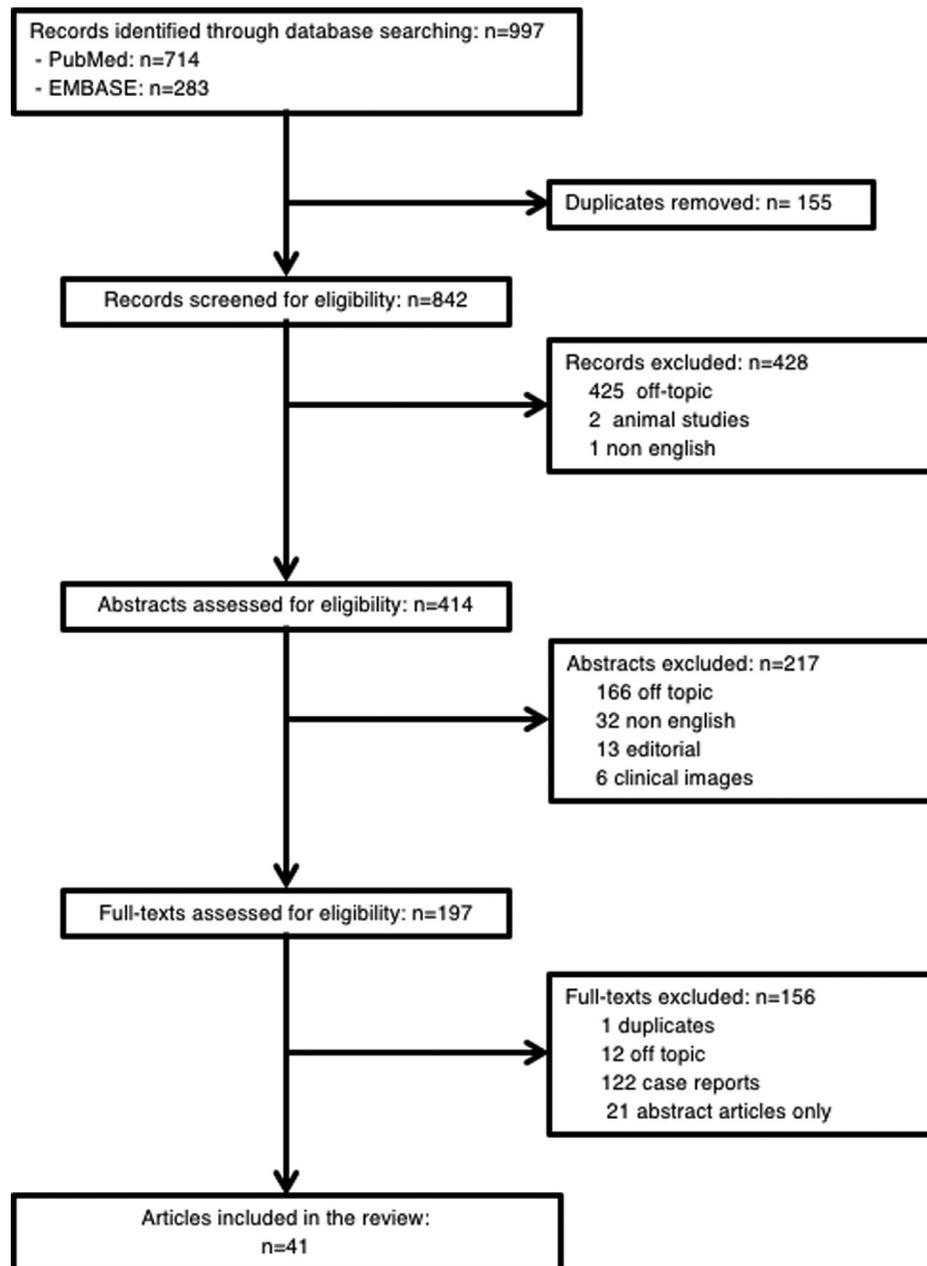


Figure 1. Study selection criteria.

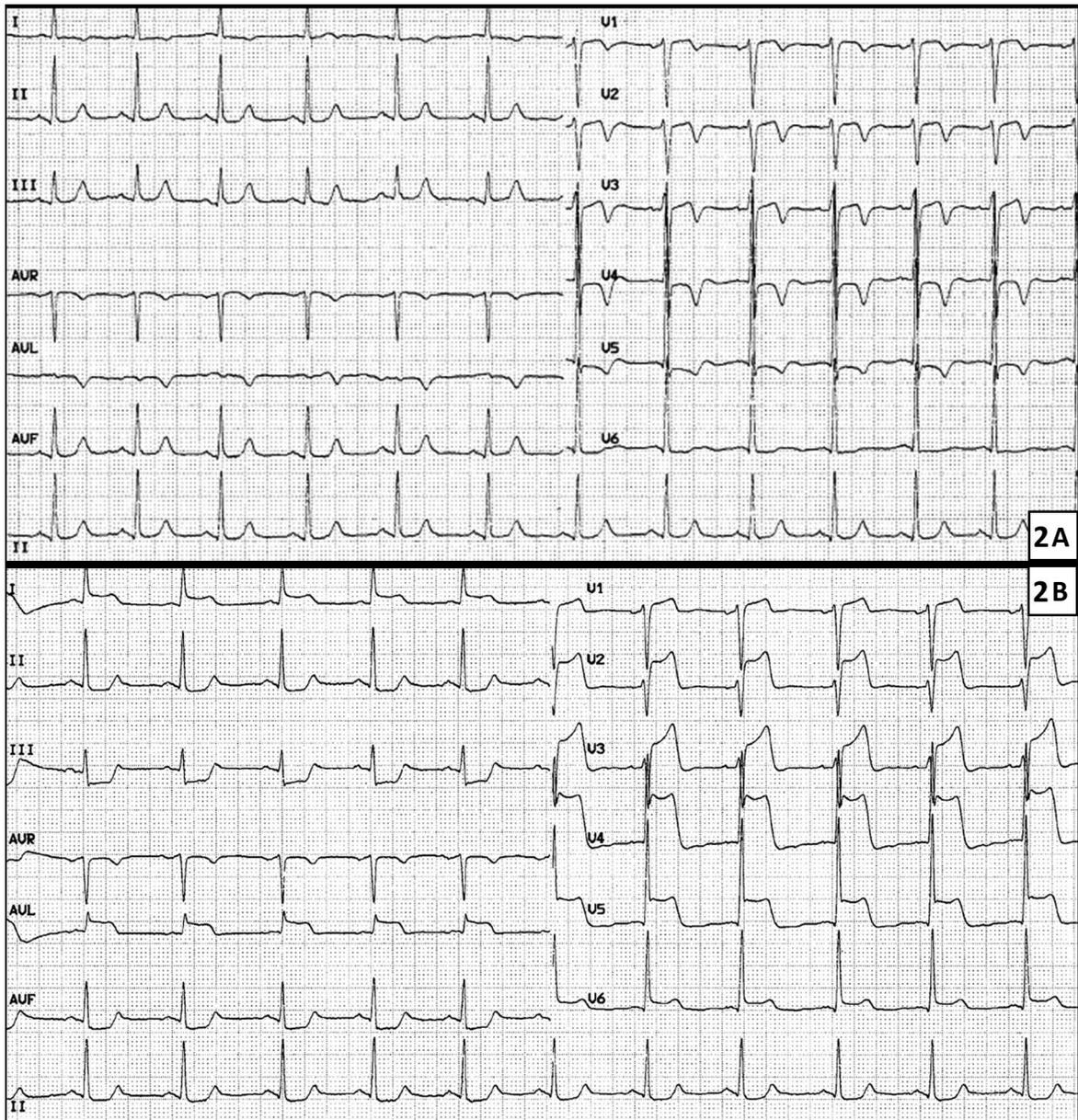


Figure 2. (A). ECG showing biphasic T waves in leads V2 and V3 without Q waves or loss of precordial R-wave progression. (B) ECG performed 1 hour later, with ST segment-elevation in V2 to V5 as well as in DI associated with ST-depression in the inferior leads compatible with an anterior myocardial infarction. Coronary angiography showed a 100% proximal left anterior descending artery occlusion.

diagnostic leads of Wellens' syndrome, T-wave inversions can extend beyond. Notably, Wellens' syndrome patients lack Q waves, loss of precordial R-wave progression or significant changes of ST segment. Wellens' syndrome suggests critical stenosis or obstruction of the proximal left anterior descending (LAD) artery with a sensitivity of 69% and specificity 89%.<sup>3</sup>

The mechanism responsible for these ECG findings is unclear. Repolarization heterogeneity resulting from reperfusion of a briefly occluded LAD could possibly explain the evolution of T-wave modifications. Dynamic negative T waves are likely to reflect edema-induced transient inhomogeneity of repolarization between apical and basal left ventricular regions.<sup>4</sup> Patients with Wellens' syndrome have a

high risk of development of extensive anterior MI and death. De Zwaan et al demonstrated that 75% of the subjects with the characteristic ECG findings who did not undergo revascularization developed anterior wall infarction within a few weeks.<sup>5</sup> In a follow-up study, the same author showed that all anginal patients with the typical Wellens' syndrome ECG findings were found to have significant proximal LAD disease. Although the majority of the studies are showing that this ECG pattern is mostly associated with critical stenosis in the LAD, in the former study, 18% of patients were having a true total LAD occlusion.<sup>2</sup> As expected, noninvasive stress testing should be avoided in this context, as increasing cardiac demand in presence of a severely narrowed LAD may lead to acute

MI.<sup>6</sup> Finally, Wellens' syndrome may also occur in normal coronary arteries following an episode of cocaine-induced vasospasm coronary spasm on the LAD.<sup>7</sup>

Described for the first time in 2008,<sup>8</sup> “*de Winter sign*” is an ECG pattern defined by the combination of: (1) tall, prominent, symmetric T waves in the precordial leads, (2) up-sloping ST segment depression >1 mm at the J-point in the precordial leads, (3) absence of ST elevation in the precordial leads, and (4) (often) mild ST segment elevation (0.5 to 1 mm) in aVR (Figure 3). In a recent systematic review, the maximal up-sloping ST depression and T-wave height peak were both found in lead V3, with a median amplitude of 0.3 mV (ST depression) and 0.9 mV (T-wave height), respectively.<sup>9</sup>

The exact electrophysiologic mechanisms involved in the observed ECG changes are unknown. According to current knowledge, this ECG pattern corresponds to a critical subocclusion of LAD—with ST-segment elevation ultimately occurring as soon as the vessel is totally occluded. The moderate ST-segment depression as well as the tall, peaked T waves is physiologically attributed to a—hypoxia driven—alteration in ATP-dependent potassium channels, resulting in a delay in repolarization in the subendocardial region, with a change in the transmembrane action potential shape.<sup>10</sup> This pattern can persist for hours, because progression toward ST elevation may be impeded by modern, aggressive antiplatelet therapy.

As many as 2% of patients with acute anterior STEMI will present with this atypical ECG pattern.<sup>8</sup> In a large cohort study of 5,588 ACS patients in a prehospital setting, an ECG compatible with “*de Winter sign*” was identified in 1.6% of all anterior infarctions (11 of 688 patients). Interestingly, 10 of 11 of those were male and proximal or mid

LAD was the culprit lesion in all cases. Due to the absence of the classical STEMI pattern, significant delays up to several days occurred in some of those patients, of whom 3 of 11 finally died.<sup>11</sup> On a broader note, in patients with ACS suspicion, *de Winter sign* presents a positive predictive value of 95% to 100% for at least 70% angiographic stenosis of a major epicardial vessel.<sup>9</sup>

Being widely recognized as a precursor sign of STEMI and imminent coronary occlusion, *hyperacute T waves* also represent a very high risk ECG presentation. Even though there is no well-established universal definition, hyperacute T waves are generally described as broad-based, symmetrical, and tall compared with the preceding R-wave (Figure 4). They are often associated with a depressed J-point and/or reciprocal ST segment depression in other ECG leads. Hyperacute T waves are most apparent in the precordial leads and more noticeable when compared with previous ECGs.

The hypothesized mechanisms involve either flow preservation due to coronary subocclusion or coronary occlusion with subsidiary blood supply through collateral vessels. In the early phase of coronary artery occlusion, the shortening of the subepicardial action potential is thought to increase the endoepicardial voltage gradient of repolarization, which generates the characteristic tall-and-peaked appearance.<sup>12</sup> When coronary occlusion occurs, hyperacute T waves are usually transient, rapidly evolving into ST-segment elevation. Performing multiple, serial ECGs in this context is of utmost importance.

With regards to the predictive ability of hyperacute T waves, after analysis of 13,393 ECGs for T-waves amplitudes greater than the standard amplitudes >0.5 mV in limb leads and >1.0 mV in precordial leads—and excluding all

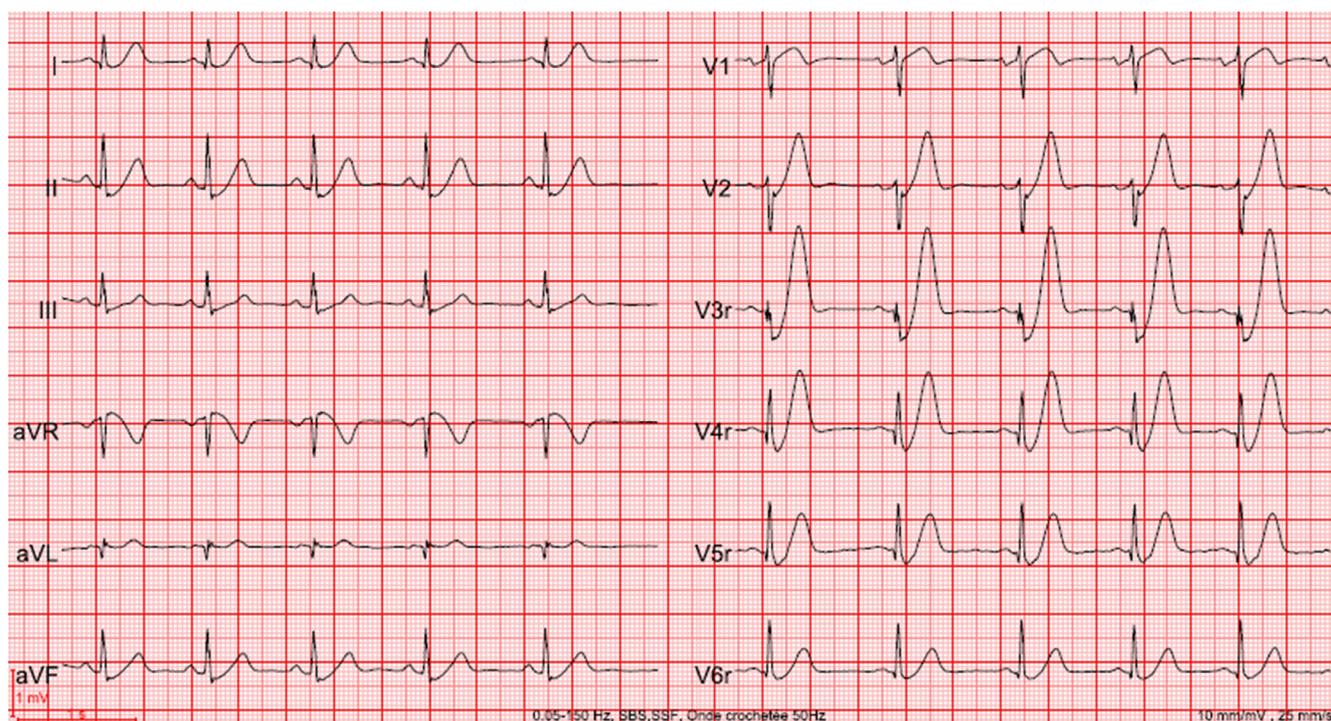


Figure 3. ECG showing up-sloping ST segment depression at the J point in leads V2 to V6, with prominent T waves in the precordial leads as well as a mild ST segment elevation in aVR.

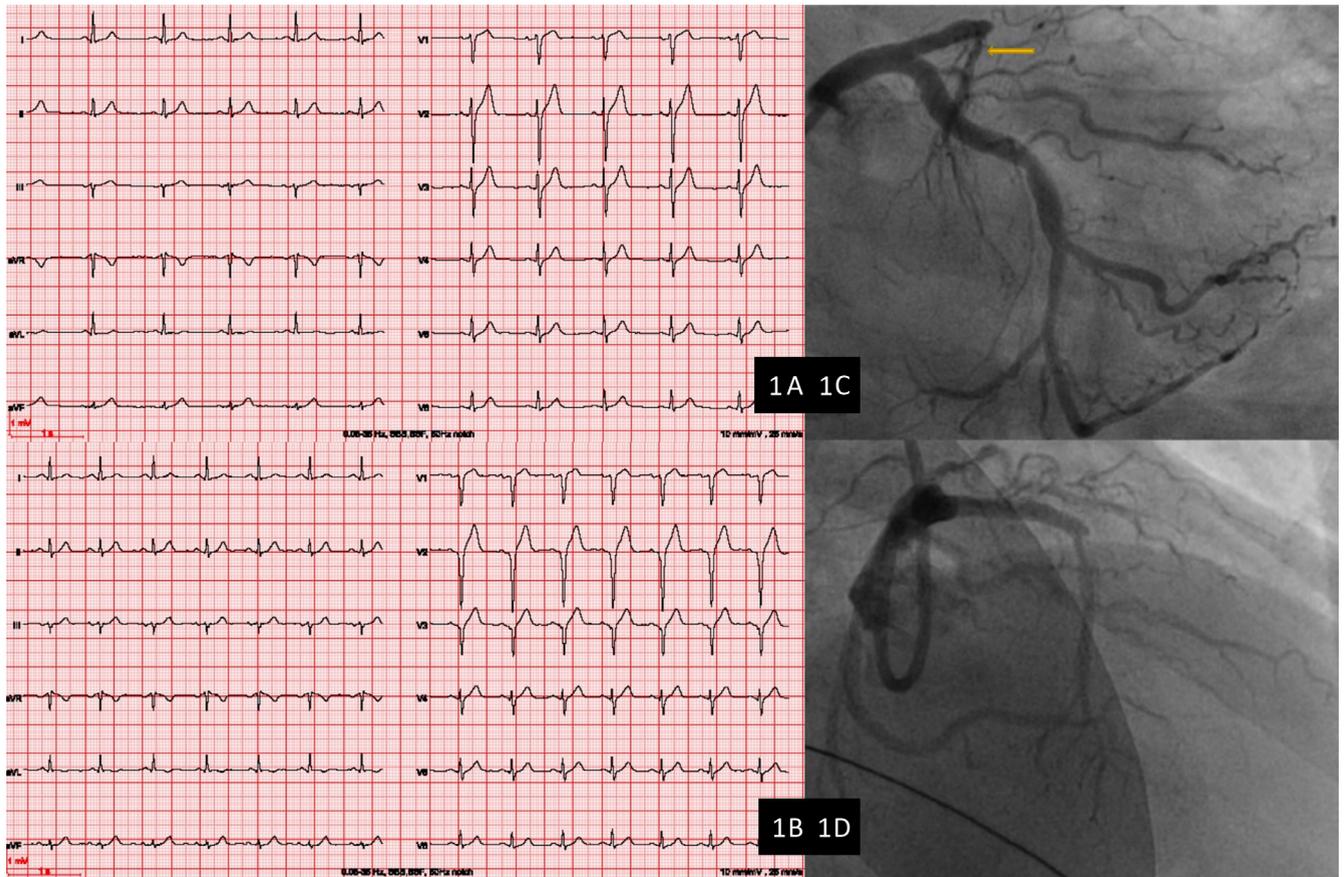


Figure 4. (A). Initial ECG of a 51-year-old patient presenting to the emergency department with acute onset of chest pain, showing hyperacute T waves without ST-segment deviation. (B) Second ECG performed 4 hour later due to persisting chest pain, now showing Q waves in leads V1-V3, prompting a coronary angiography. (C, D) Coronary angiogram demonstrating left anterior descending artery occlusion, after the 1st septal branch (yellow arrow). (Color version of figure is available online.)

secondary etiologies, the following ECG criteria were suggested: (1) a J-point position/T-wave amplitude ratio  $>25\%$ , (2) T-wave amplitude/QRS amplitude ratio  $>75\%$ , (3) J-point elevation  $>0.3$  mV.<sup>13</sup> These criteria together with patient's age  $>45$  years predicted ACS with a specificity of 98%, a sensitivity of 62%, and positive and negative predictive values of 93% and 86%, respectively.

In lead V1 specifically, where a normal T-wave is usually flat or inverted, some authors argue that a T-wave may be considered abnormal when its amplitude is taller than in V6. Other definitions (looking only at V1) include a positive deflection  $>0.15$  mV. When this criterion was applied in a series of 218 patients undergoing cardiac catheterization, 84% of them were found with a significant ( $>75\%$ ) stenosis in a major epicardial vessel. In most of those patients, the culprit lesion concerned the circumflex artery.<sup>14</sup>

The ECG differential diagnosis of hyperacute T waves is vast including—among others—hyperkalemia, early repolarization patterns, left ventricular hypertrophy, acute myopericarditis, cerebrovascular hemorrhage, as well as the chronic and evolving phase of MI. Thus, interpreting this finding in the context of suspected ACS—after narrowing down the differential diagnosis and performing multiple, serial ECGs at short time intervals is of the essence.

Although the majority of patients with chest pain and *LBBB* do not have acute MI, MI occurring in a patient with *LBBB* may remain unrecognized and be associated with adverse clinical outcomes. A recent study based on a prospective cohort database from 1997 to 2016, including 28,421 patients with established acute MI, showed that patients with *LBBB* are less likely to receive invasive treatment strategy as well as evidence-based antithrombotic regimen resulting in higher in-hospital mortality and MACE.<sup>15</sup>

According to the current guidelines, urgent reperfusion therapy is recommended in patients with new (or presumed new) *LBBB* and clinical suspicion of ongoing myocardial ischemia. Although the interpretation of ECG in the presence of previous *LBBB* is less specific than in its absence, numerous studies have evaluated ECG criteria for the diagnosis of STEMI in this context; in them Sgarbossa criteria are the most validated in clinical studies. In 1996, evaluating  $\sim 26,000$  patients from the GUSTO-1 trial, Sgarbossa et al<sup>16</sup> published 3 independent ECG criteria for the diagnosis of STEMI in the context of *LBBB* (1) ST segment elevation of  $\geq 1$  mm concordant with the QRS complex (5 points); (2) ST-segment depression of  $\geq 1$  mm in lead V1, V2, and V3 (3 points) (Figure 5); (3) STE of  $\geq 5$  mm discordant with the QRS complex (2 points). A score greater  $\geq 3$  points was found to have an excellent specificity of  $>95\%$ , while its

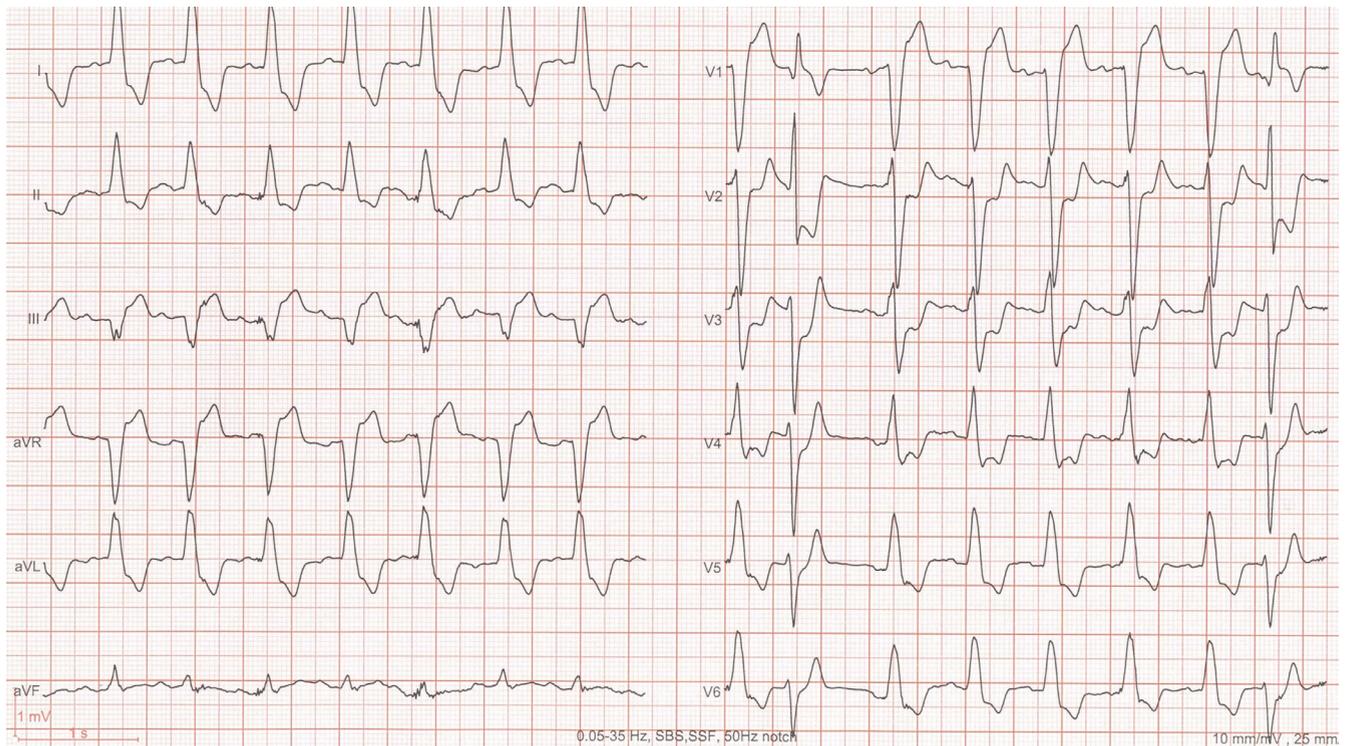


Figure 5. ECG showing ST-segment depression in leads V2, V3 of  $\geq 1$  mm, related to acute occlusion of the circumflex artery.

limited sensitivity (31% to 73%) disfavored its widespread use in clinical practice.<sup>17</sup> Thus, Sgarbossa criteria should not be used to rule out MI, but may be used to rule it in.

In 2012, Smith et al<sup>18</sup> proposed a revised algorithm in which the third Sgarbossa component (excessively discordant ST-segment elevation in the setting of a negative QRS)—the one presenting the worst sensitivity in the 3 criteria is replaced by: a ST-segment elevation to S-wave depth (ST/S ratio) of less than  $-0.25$ . In that study, application of the new criterion showed improved diagnostic performance for STEMI with a reported sensitivity and specificity of 91% and 90%, respectively. However, when this new algorithm was externally validated by Di Marco et al<sup>19</sup> in a retrospective analysis of 145 patients with LBBB and suspected MI, sensitivity was similar to that of the Sgarbossa criteria (67%), although the specificity remained high.

Conventional RV (right ventricular) pacing results in QRS morphologies similar to LBBB that—as previously discussed—limit the diagnostic accuracy of ECG in ACS. In a retrospective analysis conducted by Rathore et al between 1994 and 1996, 1.9% of 102,249 patients treated for acute MI had a RV-paced ECG pattern. These patients were notably less likely to receive emergent reperfusion therapy.<sup>20</sup> Similar results were observed in another study where in 27,985 acute MI patients, pacemaker carriers (n=300) were significantly less likely to receive emergent reperfusion therapy (58.7% vs 82.4%;  $p < 0.001$ ) and were more often treated conservatively. In-hospital mortality was significantly higher in patients with pacemaker rhythm (11.3% vs 4.6%;  $p < 0.001$ )—even though their MI size was smaller.<sup>21</sup>

In such patients, ECG assessment can be facilitated by 2 approaches (1) temporarily inhibiting pacing function in nonpacemaker dependent patients and/or (2) applying the aforementioned Sgarbossa criteria (Figure 6). When temporarily inhibiting the pacemaker function, one should bear in mind ECG changes due to a cardiac memory effect—the so-called Chatterjee phenomenon—that may complicate ECG interpretation. With regards to ECG criteria in the presence of pacemaker-induced LBBB, Sgarbossa et al applied the previously described algorithm in RV-paced patients with acute MI enrolled in the previous GUSTO trial. Although the sensitivity was low, all 3 criteria were found to be helpful for “ruling in” acute MI (1) Concordant ST elevation  $> 1$  mm in leads with a positive QRS complex (sensitivity 18%, specificity 94%); (2) Concordant ST depression  $> 1$  mm in V1 to V3 (sensitivity 29%, specificity 82%); (3) Excessively discordant ST elevation  $\geq 5$  mm in leads with a negative QRS (sensitivity 53%, specificity 88%).<sup>22</sup> Actually, compared with other scoring systems, Sgarbossa’s criteria seem to have the best predictive value to identify STEMI in pacemaker carriers.<sup>23</sup> Of note, for patients with biventricular pacing, there is no established consensus on ECG criteria for MI.

Patients with established STEMI and RBBB have a poor prognosis because the culprit lesion is commonly found in the proximal LAD (before the 1st septal branch). Contrary to the presence of LBBB, ST-T segment ECG criteria for the diagnosis of acute ischemia or infarction are traditionally considered “not affected” by the presence of RBBB. Nevertheless, in a retrospective study of 6,742 patients with acute MI,<sup>24</sup> 2/3 of patients with RBBB and no ST-segment elevation, were found to have a TIMI flow of 0 to 2 during

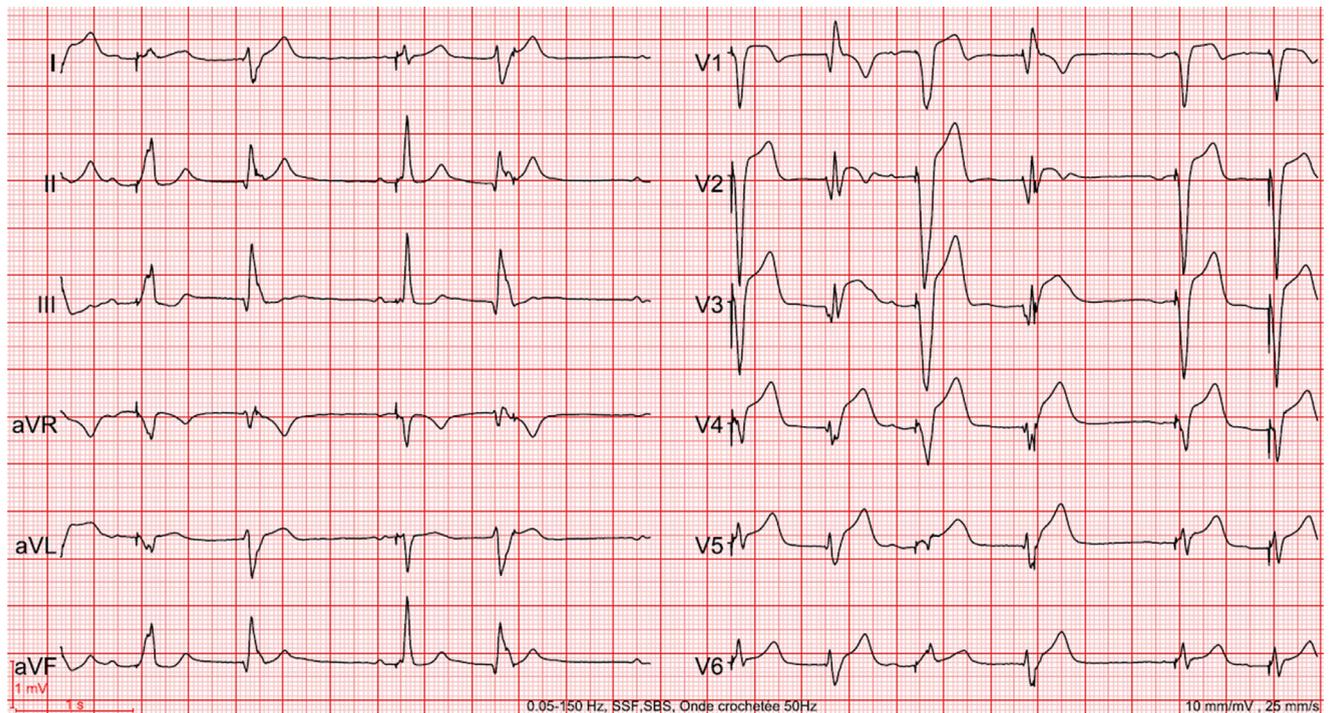


Figure 6. ECG showing a partially paced rhythm with excessive discordant ST-elevation  $\geq 5$  mm in leads with a paced negative QRS. Native QRS complexes show RBBB morphology with ST-elevation and Q waves indicating a subacute anterior myocardial infarction. A coronary angiogram revealed a thrombotic occlusion of the proximal left anterior descending artery.

follow-up coronary angiography, confirming that ST-segment interpretation cannot be used with complete safety in order to rule out STEMI.

Accordingly, when persistent ischemic symptoms are accompanied by a (presumed new) RBBB, emergent coronary angiography should be considered. In a study of 4,067 patients presenting to the emergency department with suspected ACS, 3% (125 patients) had RBBB, 7% (281) LBBB, and 1.5% (60) bifascicular block. A final diagnosis of MI was retained in 21% of those with RBBB, 29% of those with LBBB, and 23% of those with bifascicular block, whereas the mortality rate at 1 year was 11% in RBBB, 7% in LBBB, and 18% in bifascicular block patients. The authors concluded that these observations argue in favor of the updated ESC STEMI guidelines including RBBB as high risk ECG pattern for mortality in patients with suspected MI.<sup>25</sup>

## Discussion

The present article summarizes the ECG presentations, mechanisms, and clinical features of 6 distinct, very high risk, ECG patterns associated with coronary artery occlusion in patients with symptoms of ongoing myocardial ischemia.

Firstly, even in the current era of abundance of medical screening and testing, there are still a considerable amount of patients with “missed” coronary artery occlusions that never get classified as STEMI. Studies demonstrate that in about 1/4 of non-STEMIs, the infarct-related artery is occluded.<sup>26</sup> A proportion of these cases may correspond to

“STEMI equivalent” patterns, whose subtle ECG findings were diagnostic or highly suggestive of coronary artery occlusion. These patients may be “ruled-in” lately by very high biomarkers and significant wall motion abnormalities in echocardiography. Considering the above, some authors even argue that—taking into account the morbidity and mortality associated with missed diagnosis—systematic inclusion of “STEMI equivalents” in catheter laboratory activation protocols may identify patients requiring primary percutaneous coronary intervention and improve outcomes.<sup>27</sup> In such cases, early involvement of interventional cardiologists in the decision-making process is invaluable.

Secondly, given their atypical ECG manifestation beyond the classical STEMI criteria, they are often misdiagnosed leading to unnecessary delays in reperfusion therapy and adverse clinical outcomes. Although physicians and trained paramedics have a similar accuracy to identify the classic ECG STEMI patterns, they have not been systematically trained or challenged to recognize “STEMI equivalent” patterns. In addition, despite the advent of new digital ECG technology with sophisticated analytical methods, current automated diagnostic algorithms are not yet capable of facilitating the identification of these patterns. Considering the difficulty to memorize all these different patterns, we created a table (Table 1) in order to summarize the different “STEMI equivalents” ECG patterns along with their sensitivity, specificity, and predictive positive value as well as the culprit artery implicated.

Thirdly, apart from the ECG patterns described in this review, 2 additional ECG patterns that physicians should be aware of in-patients with symptoms of ongoing ischemia,

Table 1.

STEMI equivalents and their ECG presentation, along with their sensitivity, specificity and predictive value as well as the culprit artery implicated.

STEMI equivalents	ECG pattern	Sensitivity %	Specificity %	PPV %	Culprit artery*
Wellens' syndrome	Type 1: Symmetric & deeply inverted T waves in V2-V3 Type 2: Biphasic T waves in V2-V3	69%	89%	—	LAD
De Winter sign	Tall, symmetric T waves in PL Upsloping STD > 1 mm in PL Absence of STE in PL Mild STE in aVR	—	—	95.2% - 100%	LAD
High Amplitude T wave	J-point/T-wave amplitude > 25% T-wave amplitude/QRS amplitude > 75% J-point elevation >0.3 mV Patients >45 years old	69.1%	98%	93%	LAD
New LBBB	Sgarbossa criteria <sup>†,‡</sup> 1. STE $\geq$ 0.1 mV concordant with QRS (score: 5) 2. STD $\geq$ 0.1 mV in V1-V3 (score: 3) 3. STE $\geq$ 0.5 mV discordant with QRS (score: 2)	73% (64% - 80%) 25% (18% - 34%) 31% (23% - 39%)	92 (86-96) 96 (91-99) 92 (85-96)	89% (score > 3 points)	Undetermined
RV pacing	Sgarbossa criteria • 1st • 2nd • 3rd	18% 29% 53%	94% 82% 88%	—	Undetermined
New RBBB	No specific ECG pattern (same as classic RBBB)	—	—	—	LMCA/LAD

ECG = Electrocardiogram; LAD = left anterior descending coronary artery; LBBB = left bundle branch block; LMCA = left main coronary artery; OD = odd ratio; PL = precordial leads; PPV = positive predictive value; RBBB = right bundle branch block; RV = right ventricular; STD = ST-depression; STE = ST-elevation.

\* Vessel most frequently implicated in the presence of each STEMI equivalent.

<sup>†</sup> Score  $\geq$  3 points = 90% specificity for STEMI.

<sup>‡</sup> Other criteria such as the modified algorithm of Smith.

deserve merit: the “true” isolated posterior MI and the “ST elevation in lead aVR” syndrome. Considering that isolated posterior MI has a well-established ECG definition (ST-depression  $\geq$ 0.05 mV in leads V1 through V3 or/and ST-segment elevation  $\geq$ 0.05 mV in posterior leads V7 to V9 [ $\geq$ 0.1 mV in men <40 years old]), this ECG pattern was not included in this review. This standard definition (ST segment change of  $\geq$ 0.5 mm) yields a sensitivity of 94%—as compared with a sensitivity of 49% for an ST elevation of  $\geq$ 1 mm. According to the literature, despite being associated with “true” complete coronary artery occlusion of either the right coronary or the circumflex artery, a significant percentage of physicians still fail to recognize this syndrome. In a study conducted by Khan et al,<sup>28</sup> 79 of 177 (68%) physicians failed to diagnose isolated posterior MI when they were examined in their ability to identify it. In a more recent study, the median door-to-balloon time was consistently longer in patients with isolated posterior MI, resulting in less coronary reperfusion within the 90-minute target as well as longer hospital stays and in-hospital cardiovascular complications.<sup>29</sup> Recording additional posterior leads (and right precordial leads) in every ACS patient are crucial and can greatly improve the diagnostic accuracy of isolated posterior MI.

Although not typically associated with acute coronary occlusion, several studies demonstrate that ST-segment elevation in lead aVR coupled with widespread horizontal ST-depression  $\geq$ 0.1 mV in  $\geq$ 8 surface leads, is highly suggestive of 3-vessel coronary artery disease, left main coronary artery or LAD stenosis with a sensitivity of 78% to 81%, specificity of 76% to 80% and positive predictive value of 57%.<sup>30</sup> The relation between

aVR and V1 could be used to differentiate between left main coronary artery and LAD disease, where ST elevation in V1 more than in aVR indicates LAD disease whereas the opposite points to proximal left main coronary artery disease. Extensive subendocardial ischemia or infarction of the basal ventricular septum is the 2 possible evoked mechanisms responsible for the ECG changes in lead aVR. In the absence of reported cases of complete coronary occlusion, this pattern was not included in our study, but should be dealt with as a high-risk non-STEMI with possibility of imminent coronary flow compromise.

As a final note, in patients with acute MI seen very early after symptoms onset, ST-segment elevation might be absent; this is usually a transient event. In the presence of ongoing symptoms, maintaining a high-index of suspicion with serial ECG tracings as well as comparison of the current ECG with previous recordings is highly recommended in order to detect dynamic/novel changes and evolution toward classical STEMI ECG patterns. Furthermore, some patients with acute occluded coronary vessel (e.g., vein coronary artery bypass graft, circumflex artery, diagonal or marginal branch involvement) could be denied reperfusion therapy in the absence of any ST elevation or other ECG modification. In those patients, since the standard 12-lead ECG as well as the supplementary right precordial or posterior leads do not always allow early MI recognition, further risk evaluation with serial biomarkers, bedside echocardiography or even more advanced cardiovascular imaging according to local availability and expertise (e.g., coronary computed tomography) should be considered.

Again, clinical acumen is a key especially in patients with persistent symptoms of ongoing myocardial ischemia in the absence of a clear etiology for whom the appropriateness of reperfusion therapy is uncertain.

In conclusion, outside the context of classical STEMI, applying urgent reperfusion therapy to patients with symptoms of ongoing ischemia on the basis of ECG findings remains a significant challenge. We have herein summarized the existing evidence around 6 distinct ECG patterns—named as “STEMI equivalents”—that have been associated with coronary artery occlusion. In the presence of any of those ECG patterns, maintaining a high index of clinical suspicion, ordering additional studies (serial ECGs +/- biomarkers, echocardiography, and advanced imaging) and early involvement of interventional cardiologists in the decision-making process is of paramount importance. Prompt recognition of those high risks ECG syndromes by those treating ACS patients in the emergency department or prehospital setting is crucial, since primary percutaneous coronary intervention is—in most cases—warranted.

## Disclosures

Dr. Antiochos has received research funding from the SICPA Foundation, the Novartis Foundation for Medical-Biological Research and the Bangerter-Rhyner Foundation. All other authors have no declarations of interest to disclose.

- Wall J, White LD, Lee A. Novel ECG changes in acute coronary syndromes. Would improvement in the recognition of ‘STEMI-equivalents’ affect time until reperfusion. *Intern Emerg Med* 2018;13:243–249.
- de Zwaan C, Bar FW, Janssen JH, Cheriex EC, Dassen WR, Brugada P, Penn OC, Wellens HJ. Angiographic and clinical characteristics of patients with unstable angina showing an ECG pattern indicating critical narrowing of the proximal LAD coronary artery. *Am Heart J* 1989;117:657–665.
- Haines DE, Raabe DS, Gundel WD, Wackers FJ. Anatomic and prognostic significance of new T-wave inversion in unstable angina. *Am J Cardiol* 1983;52:14–18.
- Migliore F, Zorzi A, Marra MP, Basso C, Corbetti F, De Lazzari M, Tarantini G, Buja P, Lacognata C, Thiene G, Corrado D, Iliceto S. Myocardial edema underlies dynamic T-wave inversion (Wellens’ ECG pattern) in patients with reversible left ventricular dysfunction. *Heart Rhythm* 2011;8:1629–1634.
- de Zwaan C, Bar FW, Wellens HJ. Characteristic electrocardiographic pattern indicating a critical stenosis high in left anterior descending coronary artery in patients admitted because of impending myocardial infarction. *Am Heart J* 1982;103:730–736.
- Patel K, Alattar F, Koneru J, Shamoof F. ST-elevation myocardial infarction after pharmacologic Persantine Stress Test in a patient with Wellens’ Syndrome. *Case Rep Emerg Med* 2014;2014:530451.
- Langston W, Pollack M. Pseudo-Wellens syndrome in a cocaine user. *Am J Emerg Med* 2006;24:122–123.
- de Winter RJ, Verouden NJ, Wellens HJ, Wilde AA, Interventional Cardiology Group of the Academic Medical C. A new ECG sign of proximal LAD occlusion. *N Engl J Med* 2008;359:2071–2073.
- Morris NP, Body R. The De Winter ECG pattern: morphology and accuracy for diagnosing acute coronary occlusion: systematic review. *Eur J Emerg Med* 2017;24:236–242.
- Fiol Sala M, Bayes de Luna A, Carrillo Lopez A, Garcia-Niebla J. The ‘De Winter Pattern’ can progress to ST-segment elevation acute coronary syndrome. *Rev Esp Cardiol (Engl Ed)* 2015;68:1042–1043.
- de Winter RW, Adams R, Amoroso G, Appelman Y, Ten Brinke L, Huybrechts B, van Exter P, de Winter RJ. Prevalence of junctional ST-depression with tall symmetrical T-waves in a pre-hospital field triage system for STEMI patients. *J Electrocardiol* 2019;52:1–5.
- Zorzi A, Perazzolo Marra M, Migliore F, Tarantini G, Iliceto S, Corrado D. Interpretation of acute myocardial infarction with persistent ‘hyperacute T waves’ by cardiac magnetic resonance. *Eur Heart J Acute Cardiovasc Care* 2012;1:344–348.
- Collins MS, Carter JE, Dougherty JM, Majercik SM, Hodsden JE, Logue EE. Hyperacute T-wave criteria using computer ECG analysis. *Ann Emerg Med* 1990;19:114–120.
- Manno BV, Hakki AH, Iskandrian AS, Hare T. Significance of the upright T wave in precordial lead V1 in adults with coronary artery disease. *J Am Coll Cardiol* 1983;1:1213–1215.
- Erne P, Iglesias JF, Urban P, Eberli FR, Rickli H, Simon R, Fischer TA, Radovanovic D. Left bundle-branch block in patients with acute myocardial infarction: presentation, treatment, and trends in outcome from 1997 to 2016 in routine clinical practice. *Am Heart J* 2017;184:106–113.
- Sgarbossa EB, Pinski SL, Barbagelata A, Underwood DA, Gates KB, Topol EJ, Califf RM, Wagner GS. Electrocardiographic diagnosis of evolving acute myocardial infarction in the presence of left bundle-branch block. GUSTO-1 (Global Utilization of Streptokinase and Tissue Plasminogen Activator for Occluded Coronary Arteries) Investigators. *N Engl J Med* 1996;334:481–487.
- Lopes RD, Siha H, Fu Y, Mehta RH, Patel MR, Armstrong PW, Granger CB. Diagnosing acute myocardial infarction in patients with left bundle branch block. *Am J Cardiol* 2011;108:782–788.
- Smith SW, Dodd KW, Henry TD, Dvorak DM, Pearce LA. Diagnosis of ST-elevation myocardial infarction in the presence of left bundle branch block with the ST-elevation to S-wave ratio in a modified Sgarbossa rule. *Ann Emerg Med* 2012;60:766–776.
- Di Marco A, Anguera I, Rodriguez M, Sionis A, Bayes-Genis A, Rodriguez J, Ariza-Sole A, Sanchez-Salado JC, Diaz-Nuila M, Masotti M, Villuendas R, Dallaglio P, Gomez-Hospital JA, Cequier A. Assessment of Smith algorithms for the diagnosis of acute myocardial infarction in the presence of left bundle branch block. *Rev Esp Cardiol (Engl Ed)* 2016;70:559–566.
- Rathore SS, Weinfurt KP, Gersh BJ, Oetgen WJ, Schulman KA, Solomon AJ. Treatment of patients with myocardial infarction who present with a paced rhythm. *Ann Intern Med* 2001;134:644–651.
- Bertel N, Witassek F, Puhan M, Erne P, Rickli H, Naegeli B, Pedrazzini G, Stauffer JC, Radovanovic D. Management and outcome of patients with acute myocardial infarction presenting with pacemaker rhythm. *Int J Cardiol* 2017;230:604–609.
- Sgarbossa EB, Pinski SL, Gates KB, Wagner GS. Early electrocardiographic diagnosis of acute myocardial infarction in the presence of ventricular paced rhythm. GUSTO-I investigators. *Am J Cardiol* 1996;77:423–424.
- Freitas P, Santos MB, Faria M, Rodrigues G, Vale N, Teles RC, Almeida M, Mendes M. ECG evaluation in patients with pacemaker and suspected acute coronary syndrome: which score should we apply? *J Electrocardiol* 2016;49:744–748.
- Widimsky P, Rohac F, Stasek J, Kala P, Rokyta R, Kuzmanov B, Jakl M, Poloczek M, Kanovsky J, Bernat I, Hlinomaz O, Belohlavek J, Kral A, Mrazek V, Grigorov V, Djambazov S, Petr R, Knot J, Bilkova D, Fischerova M, Vondrak K, Maly M, Lorencova A. Primary angioplasty in acute myocardial infarction with right bundle branch block: should new onset right bundle branch block be added to future guidelines as an indication for reperfusion therapy? *Eur Heart J* 2012;33:86–95.
- Neumann JT, Sorensen NA, Rubsamen N, Ojeda F, Schafer S, Keller T, Blankenberg S, Clemmensen P, Westermann D. Right bundle branch block in patients with suspected myocardial infarction. *Eur Heart J Acute Cardiovasc Care* 2018. 2048872618809700.
- Wang TY, Zhang M, Fu Y, Armstrong PW, Newby LK, Gibson CM, Moliterno DJ, Van de Werf F, White HD, Harrington RA, Roe MT. Incidence, distribution, and prognostic impact of occluded culprit arteries among patients with non-ST-elevation acute coronary syndromes undergoing diagnostic angiography. *Am Heart J* 2009;157:716–723.

27. Wall J, White LD, Lee A. Novel ECG changes in acute coronary syndromes. Would improvement in the recognition of 'STEMI-equivalents' affect time until reperfusion. *Intern Emerg Med* 2016;13:243–249.
28. Khan JN, Chauhan A, Mozdiak E, Khan JM, Varma C. Posterior myocardial infarction: are we failing to diagnose this. *Emerg Med J* 2012;29:15–18.
29. Waldo SW, Brenner DA, Li S, Alexander K, Ganz P. Reperfusion times and in-hospital outcomes among patients with an isolated posterior myocardial infarction: insights from the National Cardiovascular Data Registry (NCDR). *Am Heart J* 2014;167:350–354.
30. Kosuge M, Ebina T, Hibi K, Morita S, Endo M, Maejima N, Iwahashi N, Okada K, Ishikawa T, Umemura S, Kimura K. An early and simple predictor of severe left main and/or three-vessel disease in patients with non-ST-segment elevation acute coronary syndrome. *Am J Cardiol* 2011;107:495–500.