Clinical and Prognostic Value of the Electrocardiogram in Patients With Acute Occlusion of the Left Circumflex Coronary Artery

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The utility of the electrocardiogram (ECG) in patients with acute left circumflex (LC) coronary occlusion is not established. This study aimed at determining the clinical, angiographic, and prognostic characteristics associated with the different patterns of ST-segment changes in patients with LC occlusion. A cohort of 314 patients with LC occlusion was categorized according to the admission ECG: (1) ST-segment elevation (ST-E, n=208), (2) isolated ST-segment depression in precordial leads (ST-D, n=62), and (3) negligible ST-segment changes (No-ST, n=44). Clinical variables, coronary angiography, and 30-day major adverse cardiac event (MACE) (in-hospital ventricular fibrillation, 1-month mortality, or heart failure) were compared among the three groups. As compared with No-ST, patients with ST-E or ST-D presented more advanced Killip class, higher troponin peak, lower LV ejection fraction, and were independently associated with MACE (odds ratio 5.43, 95% confidence interval 1.09 to 27.20 and odds ratio 3.39, 95% confidence interval 0.66 to 17.50, respectively). Patients with ST-D were tardily reperfused, had more often mitral regurgitation (23.1% vs 9.3% in ST-E and 3.3% in No-ST, p=0.03), and presented ST-segment elevation in leads V7 to V9 in 12 of 16 cases with available recordings. Culprit proximal LC predominated in ST-D (41.9%), distal LC in ST-E (42.8%), and obtuse marginal in No-ST (59.1%) (all p<0.01). The No-ST had smaller coronary vessels and more collaterals. In conclusion, the three ST-segment patterns of LC occlusion identify patients with different clinical, angiographic, and prognostic characteristics. Patients with ST-depression pattern require a prompt reperfusion therapy and could be better recognized by recording leads V7 to V9. **(Am J Cardiol 2017;120:1487–1494)**

Clinical management of patients with acute occlusion of the left circumflex (LC) coronary artery is often challenged by the variable patterns of the ST-segment changes recorded in the admission electrocardiogram (ECG).[1–3] Patients with isolated ST-segment depression in precordial leads or those with negligible ST-segment changes are often not submitted to emergent coronary reperfusion[4,5] and this delay will likely impair the prognosis.[6] The variety of the ECG patterns may reflect differences in infarct extension and this would entail a distinct prognostic expectancy. However, currently available data are based on small-sized studies, and these do not provide an integrative analysis of the clinical variables, admission ECG patterns, coronary angiographic findings, and outcomes.[1,7–10] The aim of this study was to determine the clinical, angiographic, and prognostic implications associated with the ECG patterns of acute LC occlusion in a large cohort of patients.

Methods

We conducted a retrospective cohort study in patients with acute myocardial infarction (AMI) admitted consecutively in our institution from June 2006 to June 2015. Patients were identified through our institutional cath-lab registry. The inclusion criteria were (1) AMI secondary to acute LC occlusion, (2) index ECG recorded within the 12 hours of symptoms, and (3) coronary angiography performed during hospital admission. The exclusion criteria were (1) previous coronary bypass graft surgery, (2) left bundle branch block or ventricular paced rhythm, and (3) lack of available admission ECG or coronary angiography. Patients had to fulfill all inclusion and none of the exclusion criteria. Myocardial infarction was defined according to the current universal definition.[11] The study protocol complied with the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the ethics committee of our institution.

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This work was supported by the CIBERCV (CB16/11/00276) and the Red de Investigación Cardiovascular (RD12/0042/0002) of the Spanish Instituto de Salud Carlos III (Spain) and by the Fondo Europeo de Desarrollo Regional (FEDER) (de European Union, EU).

The funding sources had no involvement in study design, the collection, analysis, and interpretation of data, in writing the report, or in the decision to submit the article for publication.

See page 1493 for disclosure information.

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https://doi.org/10.1016/j.amjcard.2017.07.038

Data on clinical history, physical examination, echocardiogram, and blood tests were retrieved from the hospital records and were entered in a dedicated database.

ECGs were digitized, coded for anonymity, and reviewed by 2 independent investigators blinded to clinical and coronary angiographic data. The ECG recordings were analyzed with electronic calipers (Cardio-calipers, Iconico Inc., New York) under appropriate magnification. In each ECG we analyzed the heart rhythm, heart rate, and deviation of the ST segment at the J point with respect to the PR segment level. Accordingly, patients were allocated into 3 different categories: (1) ST segment elevation of >0.1 mV in at least 2 consecutive leads (ST-E group), (2) isolated ST-segment depression of >0.1 mV in at least 2 consecutive leads from V1 to V4, or >0.05 mV in leads V2 or V3 (ST-D group), and (3) absence or ST-segment shift <0.1 mV in 2 consecutive ECG leads (No-ST group). The cut-off values for the ST-D group were taken according to international recommendations.[12]

Coronary angiographies were analyzed by 2 independent observers blinded to the clinical and electrocardiographic data. The infarct-related artery was identified by the absence of anterograde coronary blood flow and/or by the presence of local intraluminal thrombus. Flow in the culprit coronary segment was graded using the Thrombolysis in Myocardial Infarction (TIMI) trial criteria.[13] We included patients with 0/1 TIMI flow in the LC and also those with TIMI >1 who presented ST-segment elevation and evidence of LC intraluminal thrombus in the angiography. The location of the occlusion and the coronary branch distribution were determined according to the criteria of the American Heart Association[14] later modified in the Arterial Revascularization Therapies Study (ARTS) I and II trials.[15] The proximal LC segment was considered as the main stem of the vessel extending from its origin to the exit of the first obtuse marginal branch. The coronary segment below this branch was considered as the distal LC. The luminal diameter of the affected artery just below the level of the occlusion was measured using the Quantitative Coronary Assessment software (CAAS, version 5.9; Pie Medical BV, Maastrich, The Netherlands). In patients with unsuccessful reperfusion, the diameter of the culprit vessel was entered as missing value. We also analyzed the presence of associated stenosis (≥70%) in the left anterior descending and right coronary arteries, the existence of coronary collaterals, and the pattern of coronary artery dominance.

Data on the outcomes at 30 days of hospital discharge were obtained either from our institutional records or from the database of the health-care system in our country. We analyzed the occurrence of malignant ventricular arrhythmias, heart failure, and mortality.

Categorical variables were described by frequencies and percentages and statistical differences were analyzed using the chi-square test or Fisher exact test when any expected cell frequency was <5. The continuous variables were described either by the mean and standard deviation, or by the median and interquartile range. The statistical differences among the continuous variables were analyzed using the one-way ANOVA test for independent samples in case of a normal distribution, or the Kruskal-Wallis test in case of a non-normal distribution. A binary logistic regression analysis was performed to assess the association between the admission ECG pattern and the prognosis by adjusting for several main clinically meaningful variables. The No-ST group was considered the reference category. The end point for this analysis was a combined major adverse cardiac event (MACE) including in-hospital ventricular fibrillation, 1-month mortality, and 1-month heart failure. A backward stepwise method was used to identify independent risk predictors with a p <0.05 for the inclusion or deletion criterion. Multiple multivariate imputation using Chained equations method was applied when necessary (n = 15). A p value <0.05 was considered significant. All analyses were performed using SPSS (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp) and STATA (StataCorp. 2013. *Stata Statistical Software: Release 13*. College Station, TX: StataCorp LP.) software.

Results

As shown in Figure 1, 5,560 patients with AMI underwent coronary angiography between June 2006 and June 2015 in our institution. Among them, 314 fulfilled the inclusion criteria and entered in the study. In 208 cases (66.2%) the ECG showed the ST-segment elevation pattern, in 62 (19.7%) isolated precordial ST-segment depression, and in 44 (14.0%) negligible or absent ST-segment changes.

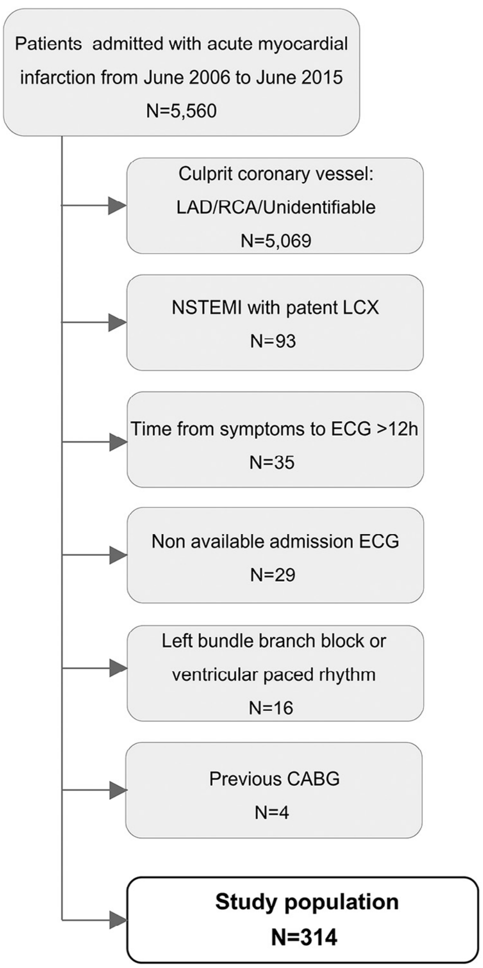

Figure 1. Flowchart of the study. CABG = coronary artery bypass graft surgery; LAD = left anterior descending coronary artery; NSTEMI = non–ST-segment elevation myocardial infarction; RCA = right coronary artery.

Table 1
Study variables of 314 patients with acute left circumflex coronary artery occlusion categorized according to three ST-segment patterns in the admission electrocardiogram

	ST-segment elevation (n = 208)	ST-segment depression (n = 62)	No ST-segment changes (n = 44)	p value
Male	170 (81.7%)	49 (79.0%)	34 (77.3%)	0.749
Age (years), mean (SD)	62.2 (13.1)	64.5 (11.9)	62.4 (13.3)	0.439
Smoker	98 (47.1%)	24 (38.7%)	13 (29.5%)	0.081
Hypertension	111 (53.4%)	32 (51.6%)	28 (63.6%)	0.407
Dyslipemia	104 (50.0%)	35 (56.5%)	28 (63.6%)	0.218
Diabetes mellitus	42 (20.2%)	14 (22.6%)	10 (22.7%)	0.881
Estimated filtration glomerular rate <60 mL/min/1.73 m^2	13 (6.3%)	6 (9.7%)	5 (11.4%)	0.407
Previous stroke	6 (2.9%)	1 (1.6%)	2 (4.5%)	0.672
Peripheral artery disease	10 (4.8%)	4 (6.5%)	1 (2.3%)	0.610
Previous myocardial infarction	21 (10.1%)	12 (19.4%)	5 (11.4%)	0.144
Heart rate (bpm), mean (SD)	78.1 (20.8)	78.5 (20.7)	70.3 (14.0)	0.051
Systolic Blood Preassure(mmHg), mean (SD)	142.0 (32.3)	140.2 (33.5)	145.7 (26.9)	0.683
Killip class > I	43 (20.7%)	10 (16.1%)	1 (2.3%)	0.013
GRACE score, mean (SD)	118 (35)	122 (35)	99 (27)	0.001
Hemoglobin (g/L), mean (SD)	140.9 (18.8)	138.3 (25.6)	141.1 (15.6)	0.974
Estimated filtration glomerular rate (mL/min/1.73 m2), mean (SD)	84.5 (26.2)	83.8 (23.8)	79.7 (24.2)	0.711
Creatine kinase peak (U/L), mean (SD)	2,979 (2,995)	2,643 (1,895)	1,290 (920)	0.002
High sensitive troponine T peak (ng/L), mean (SD)	5,565 (3,265)	5,749 (2,975)	2,551 (1,703)	0.001
Sinus rhythm	192 (92.3%)	57 (91.9%)	44 (100%)	0.128
Atrial fibrillation	15 (7.2%)	4 (6.5%)	0 (0%)	0.177
Echocardiogram				
Left ventricular ejection fraction, mean (SD)	52.6 (9.0)	53.1 (10.2)	58.6 (7.6)	0.006
Ischemic mitral regurgitation (grade II-IV)	14 (9.3%)	9 (23.1%)	1 (3.3%)	0.030
Hypokinetic left ventricle segments, mean (SD)	3.9 (2.6)	3.6 (2.6)	2.5 (2.0)	0.04
Timings				
Symptoms-to-ECG (min), median (Q1-Q3)	90 (48–180)	150 (70–300)	165 (97–296)	0.002
ECG-to-balloon (min), median (Q1-Q3)	93 (68–140)	205 (77–660)	685 (450-1,800)	<0.01

Abbreviations: ECG = electrocardiogram; SD = standard deviation.

Patients allocated into the 3 different ECG categories presented similar clinical and demographic profile (Table 1). However, as compared with the No-ST-group, patients presenting either ST-segment elevation or ST-segment depression showed (1) more advanced Killip class and the Global Registry of Acute Coronary Events (GRACE) score on admission, (2) greater creatine kinase and troponin peaks, and (3) lower left ventricular ejection fraction. Of note, moderate to severe mitral valve regurgitation was most often observed in patients with the ST-segment depression pattern.

Table 1 also shows that the time intervals between symptoms-to-ECG and ECG-to-balloon were shorter in patients with ST-segment elevation. Likewise, emergent primary coronary angioplasty protocol was activated in 95.2% of patients with ST-elevation, but only 55% in the ST-segment depression group, and 18.8% in patients with no ST-segment changes ($p < 0.01$). Double antiplatelet therapy with aspirin and adenosine diphosphate receptor blockers was instituted earlier in patients with ST-segment elevation (Supplementary Table 1).

Figure 2 illustrates typical examples of the 3 different ECG patterns of LC occlusion and the corresponding mean magnitude of the ST-segment deviation measured in all ECG lead in all patients of each group:

ST-segment elevation pattern: This was characterized by (1) upright ST-segment deviation in leads II, III, aVF, and less frequently, in leads V5 (46.6%), V6 (58.2%), and I/aVL (6%), (2) reciprocal ST-segment depression in leads V1 to V4 (44.7%, 83.6%, 67.1%, and 25.1%, respectively) with maximal expression in leads V2 (−0.17 ± 0.16 mV) and V3 (−0.13 ± 0.18 mV), and (3) ST-segment depression of less than 0.1 mV in leads aVR and aVL (55.1% and 60.6%, respectively). Of note, in 12 of 15 patients with available recordings of posterior thoracic leads V7 to V9, these depicted ST-segment elevation greater than 0.05 mV in at least one of them.

ST-segment depression pattern: Patients in this group presented (1) ST-segment depression extending throughout leads V2 to V5 with maximal deviation in lead V3 (−0.16 ± 0.13 mV) and V4 (−1.4 ± 1.2 mV) and (2) negligible ST-segment deviation in leads aVR and aVL. Of relevance, ST-segment elevation greater than 0.05 mV was observed in at least one of leads V7 to V9 in 12 of 16 patients with available recordings.

Negligible ST-segment changes: As shown in Figure 2, the mean magnitude and 95% confidence interval of the ST-segment deviation was lower than 0.05 mV in all leads.

The location of the occluded coronary segment varied significantly among the 3 groups of patients (Table 2 and Figure 3). Proximal LC occlusion was the culprit artery in 41.9% of patients with ST-depression whereas distal LC was most frequently observed in the ST-segment elevation group (42.8%). Occlusion of the obtuse marginal occurred in 59.1% of patients with no ST-segment changes and they presented smaller diameter of the culprit artery and exhibited more coronary collaterals than patients with ST-elevation or ST-depression. The coronary dominance pattern and the presence of associated coronary stenosis were similar among the 3 groups. Likewise, the success rate of the coronary intervention,

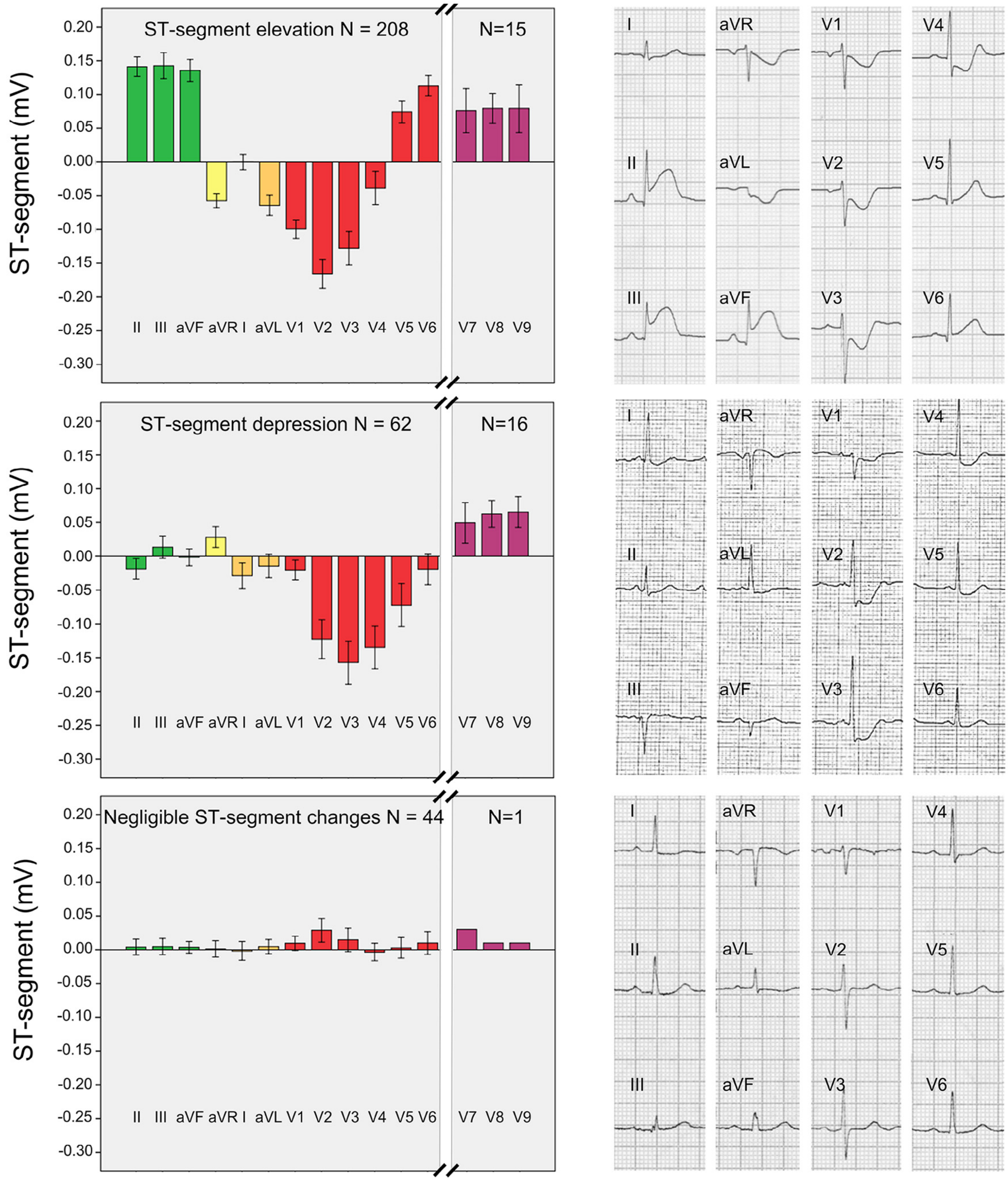

Figure 2. Electrocardiographic findings in 314 patients with acute left circumflex coronary artery occlusion categorized according to the admission ST-segment changes. The 3 panels on the left show graphically *(bars)* the mean (SE) values of the ST-segment potential in the 12 conventional leads (and in leads V7 to V9 when available) corresponding to patients with acute circumflex coronary artery occlusion. From top to bottom these panels correspond to the 3 groups of patients classified according to the admission ST-segment pattern. The three 12-lead ECG on the right correspond to representative cases in each group.

the need for intracoronary thrombectomy, and the type of the implanted stent were also comparable (Table 2).

Patients with ST-elevation and ST-segment depression had similar incidence of in-hospital heart failure, 1-month mortality, and MACE (Table 3 and Figure 4). In contrast, the episodes of ventricular fibrillation were more frequently observed in the ST-segment elevation group. Patients with no ST-segment changes presented better outcomes and none of them died during the follow-up. After a logistic binary regression analysis adjusting for the troponin peak, the lower left ventricular ejection fraction, and reperfusion time delay, ST-elevation and ST-depression patterns were independently associated with the incidence of 1-month MACE (odds ratio 5.43, 95% confidence interval 1.09–27.20 and odds ratio 3.39, 95% confidence interval 0.66–17.50, respectively).

Discussion

This is the most systematic analysis of the clinical and prognostic value of the ECG in a large cohort of patients with

Table 2
Coronary angiographic and procedural characteristics of 314 patients with acute left circumflex coronary artery occlusion categorized according to three ST-segment patterns in the admission electrocardiogram

	ST-segment elevation (n = 208)	ST-segment depression (n = 62)	No ST-segment changes (n = 44)	p value
Coronary angiographic findings				
Left coronary dominance	34 (16.3%)	6 (9.7%)	6 (13.6%)	0.411
Three-vessel coronary disease (>70%)	19 (9.1%)	8 (12.9%)	5 (11.4%)	0.664
One-vessel coronary disease,	129 (62.0%)	33 (53.2%)	28 (63.6%)	0.412
Concomitant RCA stenosis (>70%)	47 (22.6%)	22 (35.5%)	11 (25.0%)	0.123
Concomitant LAD stenosis (>70%)	51 (24.5%)	15 (24.2%)	10 (22.7%)	0.969
Infarct related artery				
Proximal LC	52 (25.0%)	26 (41.9%)	4 (9.1%)	0.001
Distal LC	89 (42.8%)	17 (27.4%)	12 (27.3%)	<0.001
Obtuse Marginal/Intermediate artery	49 (23.6%)	17 (27.4%)	26 (59.1%)	<0.001
Other arteries*	18 (8.7%)	2 (3.2%)	2 (4.5%)	0.284
Culprit artery diameter (QCA, mm), mean (SD)	2.7 (0.5)	2.7 (0.4)	2.4 (0.5)	<0.001
Coronary collaterals	19 (9.4%)	12 (19.4%)	17 (38.6%)	<0.001
Successful percutaneous coronary intervention	190 (91.3%)	53 (85.5%)	37 (84.1%)	0.187
Intracoronary thrombus	167 (80.7%)	52 (83.9%)	34 (77.3%)	0.693
Intracoronary thrombus aspiration	126 (60.9%)	37 (59.7%)	22 (50.0%)	0.410
Stent diameter	2.9 (0.5%)	2.8 (0.4%)	2.6 (0.3%)	<0.001
Bare metal stent	123 (66.1%)	35 (64.8%)	20 (55.6%)	0.675
Drug eluting stent	61 (32.8%)	19 (35.2%)	16 (44.4%)	

Abbreviations: LAD = left anterior descending coronary artery; LC = left circumflex coronary artery; QCA = quantitative coronary analysis; RCA = right coronary artery.

* Other arteries: left posterolateral or left posterior descending artery.

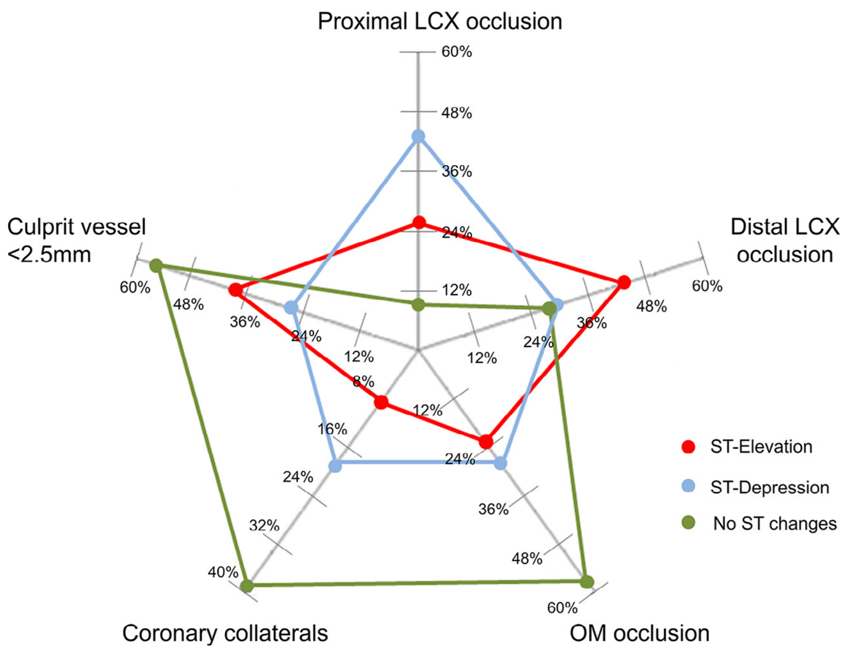

Figure 3. Graphic illustration of relevant coronary angiographic findings in 314 patients with acute left circumflex coronary artery occlusion. Radial graph depicting the differential profile of the angiographic characteristics among the 3 groups of patients categorized according to the ST-segment pattern on admission. OM = obtuse marginal coronary artery.

acute occlusion of the LC coronary artery. The 3 different ST-segment patterns observed in the admission ECG (ST-segment elevation, isolated depression, and no change) distinguished patients at high and low risk of extensive infarction, heart failure, malignant ventricular arrhythmias, and MACE.

The diagnosis of acute LC occlusion is often hampered by the absence of ST-segment elevation in the admission ECG.[16] Like in other studies,[1,2] about 20% of our patients presented the ST depression pattern and 14% did not show appreciable ST-segment changes. The clinical consequences of a delayed recognition of LC occlusion have not been

Table 3
Clinical events in 314 patients with acute left circumflex coronary artery occlusion categorized according to three ST-segment patterns in the admission electrocardiogram

	ST-segment elevation (n = 208)	ST-segment depression (n = 62)	No-ST-segment changes, (n = 44)	p value
Bradyarrhythmia	20 (9.6%)	3 (4.8%)	2 (4.5%)	0.400
Atrial fibrillation	29 (14.2%)	7 (11.5%)	4 (9.3%)	0.634
Sustained ventricular tachycardia/fibrillation	33 (16.1%)	5 (8.2%)	0 (0.0%)	0.008
Post-infarction angina	12 (5.9%)	2 (3.3%)	3 (6.8%)	0.678
In-hospital stay (days), median (Q1-Q3)	5 (4–8)	5 (4–7)	5 (3–7)	0.117
1-month heart failure	36 (18.1%)	10 (16.4%)	2 (4.8%)	0.083
1-month mortality	12 (5.9%)	3 (5.0%)	0 (0%)	0.268
MACE	57 (27.4%)	13 (21.0%)	2 (4.5%)	0.004

Abbreviations: MACE = combined endpoint including pre-admission/in-hospital ventricular fibrillation, in-hospital/30day heart failure and in-hospital/30day mortality.

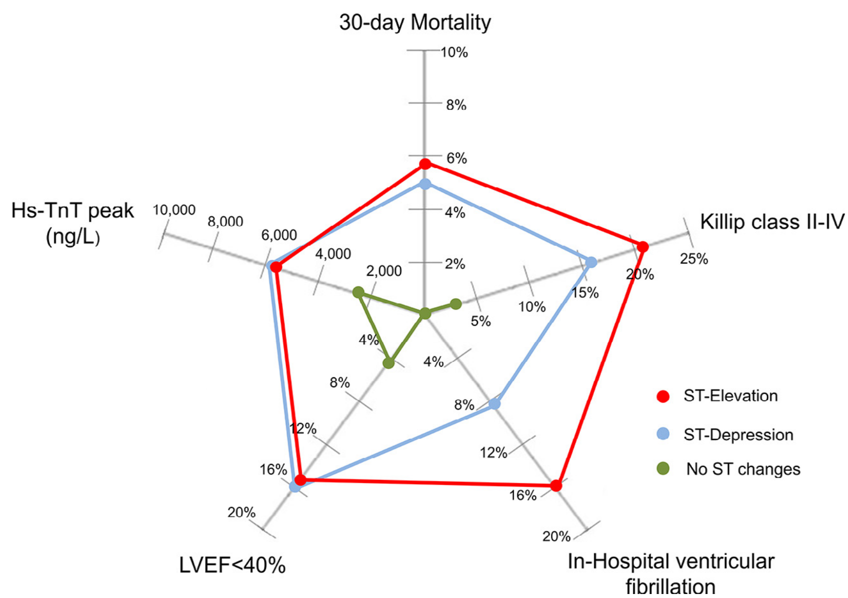

Figure 4. Graphic illustration of relevant clinical variables and events in 314 patients with acute left circumflex coronary artery occlusion. Radial graph depicting the differential clinical and prognostic profile among the 3 groups of patients categorized according to the ST-segment pattern on admission. Hs-TnT = high-sensitive troponin T; LVEF = left ventricular ejection fraction.

systematically evaluated. We found that ST-segment elevation pattern was an independent predictor of MACE and identified those patients with larger infarcts and worse outcomes. Moreover, patients with ST-segment depression were also at high-risk of in-hospital heart failure, mitral valve regurgitation, and 30-day mortality. These patients were tardily reperfused, thus prolonged ongoing ischemia likely accounted for their unfavorable prognosis. Large infarcts and high 30-day mortality were also observed in a series of patients with LC occlusion who presented isolated ST segment depression in leads V1 to V4 and were not emergently revascularized.[17] Patients with negligible ST-segment changes had better prognosis despite being tardily reperfused. As a plausible compensatory mechanism, they possess more coronary collaterals, and the culprit vessel is often an obtuse marginal branch supplying less extensive myocardial areas.

The circumstances leading to the different ST-segment patterns of LC occlusion have not yet been characterized. The lack of ST-segment elevation could reflect a low sensitivity of the ECG detecting infero-lateral left ventricular (LV) myocardial ischemia, but it may also deal with the site of the LC occlusion and/or the spatial location of the myocardial ischemic region.[18] In favor of a potential low sensitivity of the ECG, a simultaneous recording of an intracoronary ECG lead and the surface ECG during catheter balloon occlusion of the LC in 19 patients showed ST-segment elevation in the intracoronary recordings in all cases but only 32% of cases in the surface ECG.[19] In relation to the site of vessel occlusion, we found that proximal LC occlusion was more frequently observed in patients with ST-segment depression, whereas distal LC occlusion more often occurred in patients with ST-segment elevation. Obtuse marginal occlusion predominate in patients with no ST-segment changes and, of notice, they had smaller culprit arteries and more abundant coronary collaterals. Therefore, our data indicate that the location and size of the culprit artery and the presence of collaterals likely play a major role on the genesis of the different ST-segment patterns in patients with acute LC occlusion.

Our data strengthen the clinical usefulness of the admission ECG in patients with acute occlusion of the LC coronary artery. Indeed, the categorization of patients with LC occlusion based on the admission ST-segment patterns would permit a rapid risk stratification. Specifically, patients with ST-segment depression developed large infarcts, ventricular arrhythmias, and heart failure; thus, they should be reperfused as urgently as patients with ST-segment elevation. ST-segment depression in precordial leads is not exclusive of LC occlusion as it may be observed in the setting of LV subendocardial ischemia. It has been reported that in the case of LC occlusion, the ST depression is more marked in leads V2 to V4, whereas in LV subendocardial ischemia the ST-segment depression is more apparent in leads V4 to V6.[20] Previous studies analyzing the utility of leads V7 to V9 in patients with AMI have reported only a modest improvement in the diagnostic accuracy.[2,21] However, our data indicate that routine recording of leads V7 to V9 would allow recognition of LC occlusion when the admission 12-lead ECG only depicts an ST-segment depression pattern. Moreover, because a quarter of our patients with the ST-segment depression pattern presented associated mitral valve regurgitation, it is predictable that a prompt reperfusion might mitigate the mitral valve dysfunction and this in turn, prevent or delay subsequent LV remodeling.

Because this is a retrospective single-center study, there might be missing values in study variables and lost or low quality of the admission ECG and coronary angiography. To avoid these limitations, our patients were recruited consecutively and we excluded all of those with no available index ECG or coronary angiography. Moreover, to increase the accuracy of our data, we measured the ECG parameters using electronic calipers on magnified digitized ECGs. All coronary angiographic studies were purposely reanalyzed by experienced cardiologists.

Disclosures

The authors have no conflicts of interest to disclose.

Supplementary Data

Supplementary data related with this article can be found, in the online version, at https://doi.org/10.1016/j.amjcard.2017.07.038.

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