American Journal of Emergency Medicine 37 (2019) 1242–1247

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Original Contribution

Diagnostic accuracy of prehospital electrocardiograms interpreted remotely by emergency physicians in myocardial infarction patients

Alain Tanguay, MD [a,b,1], Johann Lebon, PhD [a,b,*,1], Eric Brassard, MD [c], Denise Hébert, BSc [a], François Bégin, MD [b,d]

[a] *Unité de Coordination Clinique des Services Préhospitaliers d'Urgence (UCCSPU), 143 Rue Wolfe, Lévis, Québec G6V 3Z1, Canada*
[b] *Centre de Recherche de l'Hôtel-Dieu de Lévis, 143 Rue Wolfe, Lévis, Québec G6V 3Z1, Canada*
[c] *Faculté de Médecine Université Laval, 2325 Rue de l'Université, Québec, Québec G1V 0A6, Canada*
[d] *Département de Médecine d'Urgence, Hôtel-Dieu de Lévis, 143 Rue Wolfe, Lévis, Québec G6V 3Z1, Canada*

A R T I C L E I N F O

Article history:
Received 12 July 2018
Received in revised form 29 August 2018
Accepted 5 September 2018

Keywords:
Prehospital
STEMI
Electrocardiogram
Diagnostic accuracy
Angiography

A B S T R A C T

Background: Prehospital 12 lead electrocardiogram (ECG) is the most widely used screening tool for recognition of ST-segment elevation myocardial infarction (STEMI). However, prehospital diagnosis of STEMI based solely on ECGs can be challenging.
Objectives: To evaluate the ability of emergency department (ED) physicians to accurately interpret prehospital 12 lead ECGs from a remote location.
Methods: All suspected prehospital STEMI patients who were transported by EMS and underwent angiography between 2006 and 2014 were included. We reviewed prehospital ECGs and grouped them based on: 1) presence or absence of a culprit artery lesion following angiography; and 2) whether they met the 3rd Universal Definition of Myocardial Infarction. We also described characteristics of ECGs that were misinterpreted by ED physicians.
Results: A total of 625 suspected STEMI cases were reviewed. Following angiography, 94% (590/625) of patients were found having a culprit artery lesion, while 6% (35/625) did not. Among these 35 patients, 24 had ECGs that mimicked STEMI criteria and 9 had non-ischemic signs. Upon ECG reinterpretation, 92% (577/625) had standard STEMI criteria while 8% (48/625) did not. Among these 48 patients, 35 had ischemic signs ECGs and 13 did not. Characteristics of misinterpreted ECGs included pericarditis, early repolarization, STE > 1 mm (1 lead only), and negative T-wave.
Conclusions: Remote interpretation of prehospital 12 lead ECGs by ED physicians was a useful diagnostic tool in this EMS system. Even if the rate of ECG misinterpretation is low, there is still room for ED physicians operating from a remote location to improve their ability to accurately diagnose STEMI patients.

1. Introduction

In accordance with current prehospital guidelines and recommendations of the American Heart Association (AHA) for diagnosis and emergency management of suspected ST-segment elevation myocardial infarction (STEMI) patients [1], emergency medical services (EMS) systems have developed a growing number of protocols and strategies that rely on the use and interpretation of prehospital 12 lead electrocardiograms (ECGs) [2-4].

This technology has been demonstrated to be an effective tool for emergency diagnosis and management of suspected STEMI patients who commonly require treatment through fibrinolysis or percutaneous coronary intervention (PCI) [2,4-7]. Interpretation of prehospital ECGs may be performed manually by emergency medical technicians (EMTs), electronically via computerized interpretation, remotely by emergency department (ED) physicians or cardiologists, or through a combination of these methods [2,8,9].

Physicians who remotely interpret prehospital ECGs often base their STEMI diagnoses (or lack thereof) solely on their reading of the ECG. Rates of STEMI misdiagnosis in the literature (regardless of acquisition type and interpretation method) range between 7.2% and 36% [10-14]. There are two main reasons for STEMI misdiagnosis. First, there are limitations to using 12-lead ECG as a diagnostic tool since subtle ST-segment elevations (STEs) or QRS repolarization abnormalities that obscure or mimic STE are not easily detectable on ECGs [15]. Second, while standard ECG criteria for STEMI diagnosis is well established [16], physicians interpreting ECGs may overcall STEMI diagnoses (false-positive) rather than risk missing one [10-15,17]. Additionally, there is often a short window during which physicians must make their diagnosis. Finally, in

* Corresponding author: Unité de Coordination Clinique des Services Préhospitaliers d'Urgence (UCCSPU), 143 Rue Wolfe, Lévis, Québec G6V 3Z1, Canada.
E-mail address: Johann.Lebon@USherbrooke.ca (J. Lebon).
[1] These authors contributed equally to the study.

https://doi.org/10.1016/j.ajem.2018.09.012
0735-6757/

situations where ECG interpretation is performed remotely, physicians must diagnose patients without physically examination or review of their full medical records or previous ECGs [12].

In accordance with AHA recommendation [1], in the eastern province of Québec, an EMS system has been developed where prehospital 12 lead ECGs are remotely interpreted by ED physicians at an online medical control (OLMC) center [18]. The diagnostic accuracy of remote ECG interpretation by these ED physicians is unknown. Our objective was to evaluate the accuracy of prehospital 12 lead ECG interpretation by ED physicians in this EMS system when compared to the results of angiography and to the 3rd Universal Definition of Myocardial Infarction [16]. In addition, we sought to identify characteristics of ECGs that were misinterpreted.

2. Methods

2.1. Study design and setting

The Unité de Coordination Clinique des Services Préhospitaliers d'Urgence (*UCCSPU*) STEMI detection program has been described previously [18]. Briefly, it is part of the clinical telemedicine platform program that serves the 15,000 km^2 of the Chaudière-Appalaches region (Québec, Canada) and the 21,000 km^2 of Québec City (Québec, Canada). This platform was designed to improve prehospital and community health care for rural and semi-urban citizens by providing online medical support and assistance to Basic Life Support - Emergency Medical Technicians (BLS-EMTs) for all patients in Chaudière-Appalaches (pop. 418,000) and greater Québec City (pop. 725,000) [18]. This model of care delivery and prehospital assessment was implemented in 2006 in Chaudière-Appalaches and during 2012 in greater Québec City. The program was designed to rapidly identify suspected STEMI among non-traumatic chest pain patients from a remote location so they could be quickly transported to the appropriate institution, either the nearest local hospital or a PCI center located in Québec City (*Institut universitaire de cardiologie et de pneumologie de Québec* [*IUCPQ*], Québec, Canada) [18]. This program was developed to meet the established recommendations for reperfusion delay in the treatment of STEMI patients. Details on the STEMI detection protocol and the STEMI system activation can be found in our previous publications [18].

2.2. Study population and data collection

The present study was approved by the research ethics committee of the IUCPQ and the Centre de Recherche de l'Hôtel-Dieu de Lévis (Hôtel-Dieu de Lévis Research Center), Lévis, Québec. We included suspected STEMI patients of the Chaudière-Appalaches and Québec City regions who were diverted from the field to the IUCPQ PCI center in Québec City between November 2006 and November 2014.

Patients with missing or incomplete records were excluded. Patients were also excluded if their angiographies were cancelled due to medical reasons such as severe co-morbidities (e.g., dementia, neoplasia, heart failure, cardiac arrest), advanced age (i.e., >90 years) or palliative reasons. Patients were also excluded if the cardiologist at the PCI center disagreed with the remote STEMI diagnosis made by the ED physician at the OLMC center. Eligible patients were those who underwent angiography based on remote interpretation of the inciting ECG by ED physicians (based on the 2nd or 3rd Universal Definition of Myocardial Infarction, depending on when the diagnosis was made) and whose angiographies included the presence or absence of a culprit coronary artery lesion. Based on the coronary angiography report, a culprit coronary artery lesion was defined as either the presence of an acute total or subtotal occlusion of a coronary artery with a visible thrombosis and a Thrombolysis in Myocardial Infarction Score equal to zero (0) or grade III flow in all vessels, as well as the presence of a significant coronary lesion with visible signs of acute plaque rupture in the artery where the STEMI originated. A normal coronary angiography is generally defined as no lesion or a lesion under 50% with no signs of acute occlusion [13,14,16]. Moreover, clinical data and laboratory values of cardiac biomarkers (Troponin T or Troponin I) were manually collected for all patients from the UCCSPU and IUCPQ medical records.

Study patients who were diverted to the PCI center and underwent angiography were grouped as either having "culprit artery lesion" or having "no culprit artery lesion". Following de-identification, all inciting ECGs (regardless of the year the diagnosis was made), were exhaustively reviewed and reinterpreted by an ED physician (A.T.) based on the 3rd Universal Definition of Myocardial Infarction (defined in 2012) [16]. This reviewer was aware of the origin of the ECGs; however he had no knowledge of the study objective. He was instructed only to review the ECGs and determine if they met criteria for a clear STEMI diagnosis based solely on the 3rd Universal Definition of Myocardial Infarction.

If there was a disagreement between the interpretation of A.T. and the original reading made remotely by ED physicians on duty at the OLMC center, a second ED physician (F.B.) was consulted to review the inciting ECG. This second reviewer had access to all 12 lead ECGs tracings in question, and was blinded from the study objective and from the origin of these ECGs. Similar to the first reviewer, the second reviewer (F.B.) was asked "to focus on the ECGs and see if they meet criteria for a clear STEMI diagnosis" without any clinical details provided. For any inciting ECGs that the first and second reviewers did not agree on, the final decision was based on two concordant readings. ECGs were then classified according to STEMI criteria: 1) ECG with "standard STEMI criteria", characterized by an obvious STE; or 2) ECG with "incomplete STEMI criteria". The latter was based on the final diagnosis made by the interventional cardiologist and recorded in the patient medical record as either ischemic signs (STE on 1 lead, STE < 1 mm, ST-depression or a negative T-wave) or a non-ischemic ECG. Aside from Sgarbossa ECG patterns, left bundle branch block (LBBB) patients were excluded, since it was not possible to compare their ECGs with previous ECGs.

2.3. Statistical analysis

Continuous variables are presented as mean $\pm$ standard deviation (SD) and categorical variables are reported as absolute frequencies (n) and percentages (%). Simple descriptive statistics were used to report patient characteristics, diagnoses, and ECG characteristics. To determine the diagnostic accuracy of ED physicians at the OLMC center, ECGs were first classified based on whether there was presence of a clear culprit artery lesion, and subsequently based on whether they met the 3rd Universal Definition of Myocardial Infarction. All analyses were performed using SPSS version 20.0 (Chicago, IL, USA).

3. Results

During the study period, among all suspected STEMI patients rerouted to the PCI center for angiography, 625 were eligible for final analysis after excluding those missing or having incomplete records ($n = 15$) and those having angiography cancelation ($n = 33$) by the cardiologist upon arrival at the PCI center (17 for palliative or medical reasons or advanced age; 16 for non-confirmation of the initial diagnosis) (Fig. 1).

Characteristics of the study population are shown in Table 1. Eligible patients ($n = 625$) were predominantly male (470/625; 75%) with a mean age of 63.5 $\pm$ 12.4 years (median age $= 63$ years). Cardiac biomarkers were positive in 94% (590/625) and negative in 5% (32/625) of patients.

The diagnostic accuracy of prehospital ECGs remotely interpreted by ED physicians is shown in Fig. 2. Following angiography, 94% (590/625) of patients with suspected STEMI were classified as having a culprit artery lesion, while 6% (35/625) had no culprit artery lesion. Among the 35 patients whose ECGs were misinterpreted, 69% (24/35) had ECGs that mimicked STEMI criteria, and 31% (11/35) with ECGs characterized

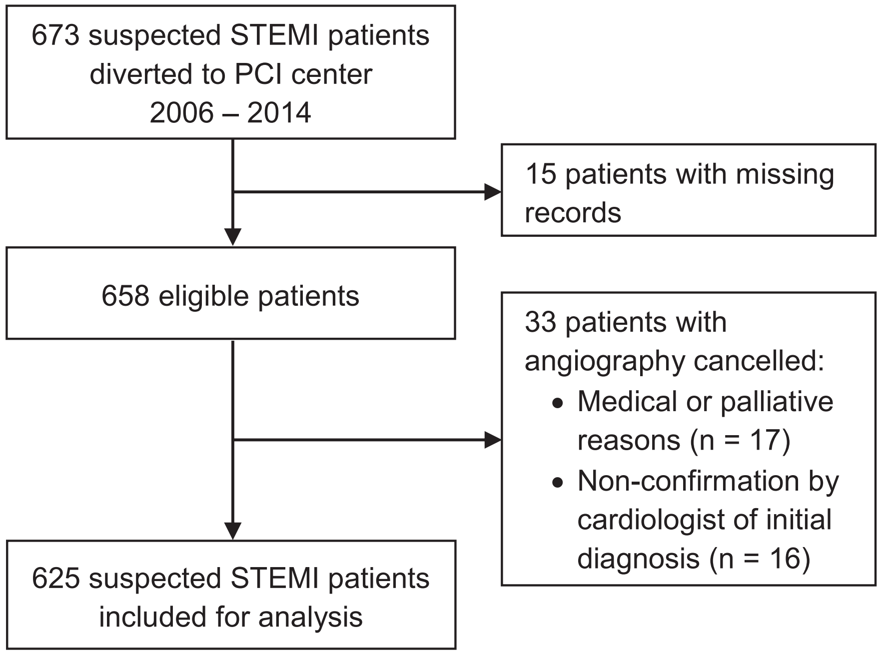

Fig. 1. Selection of study participants. STEMI = ST-segment elevation myocardial infarction; PCI = P Percutaneous coronary intervention.

as either ischemic ($n = 2$) or non-ischemic ($n = 9$). Following the 3rd Universal Definition of Myocardial Infarction, clear standard STEMI criteria were found in 92% (577/625) of patients, while 8% (48/625) had ECGs with incomplete STEMI criteria. Of these 48 patients with incomplete STEMI criteria, 73% (35/48) had ischemic signs and 27% (13/48) had non-ischemic signs. Disagreement between the first and second reviewer occurred in 4.5% of cases, and the rate of disagreement between the first reviewer and the original reading by the ED physician at the OLMC center was 10.7%.

Table 2 presents the final diagnosis made by the interventional cardiologist following angiography of 24 patients whose ECGs mimicked standard STEMI criteria but lacked a clear culprit artery lesion. The most common diagnosis in these 24 patients were pericarditis (58%), early ST-segment repolarization (29%), angina (8%), and syncope (4%).

Finally, Table 3 describes characteristics of ECGs among the 48 patients with incomplete STEMI criteria. Patients with ischemic signs ($n = 35$) had their ECGs characterized by a STE > 1 mm in only 1 lead (13/35; 37%), a STE in aVR only (6/35; 17%), a ST-segment depression (5/35; 14%), a STE < 1 mm (5/35; 14%), or a negative T-wave (5/35; 14%). Those with non-ischemic signs ($n = 13$) had their ECGs commonly characterized by non-specific ST-segment changes (10/13; 77%). Of these 48 patients, 85% should have been diverted to the nearest facility instead of being diverted to the PCI center. The remaining 15% would have been transported to the PCI center because it was the closest facility for these patients.

Table 1
Characteristics of study population.

Variable	Suspected STEMI patients ($n = 625$)
Mean age, years ± SD	63.5 ± 12.4
Male gender	470 (75)
Cardiac biomarkers[a]	
Positive	590 (94)
Negative	32 (5)
Not available	3 (1)
Diabetes	103 (17)
Hypertension	298 (48)
Dyslipidemia	352 (56)
History of coronary disease	134 (21)
Smoker	178 (29)

SD = standard deviation.
Data are presented as n (%) unless otherwise noted.
[a] Either Troponin T or Troponin I.

4. Discussion

Our retrospective analysis of suspected STEMI patients revealed that prehospital 12 lead ECGs were accurately interpreted in 94% of all cases originally diagnosed as STEMI when compared to the results of angiography, and in 92% when compared with ECG reinterpretation by our reviewers. Although some ECGs were misinterpreted due to patterns that mimicked STEMI criteria or had an obscure STE, this occurred in relatively few cases. Our findings demonstrate that remote ECG interpretation and STEMI diagnosis by ED physicians is reasonably accurate with a misinterpretation rate of <8% and that prehospital 12 lead ECG may be a critical and successful component of an integrated system dedicated for infield STEMI detection.

The results of our study are similar to findings from several previous publications which confirmed the utility of prehospital 12 lead ECG as a rapid identification tool for optimal management and treatment of suspected STEMI patients [4-7,19,20]. However, some reports have not supported remote interpretation of prehospital 12 lead ECGs by ED physicians [9,11,12]. McCabe et al. stated that prehospital 12 lead ECG cannot be considered a reliable and useful "stand-alone" diagnostic tool as it lacks sensitivity and specificity with considerable variation in ECG interpretations by different physicians [12]. These authors hypothesized that strategies relying predominantly on remote ECG interpretation with scant clinical information to establish a STEMI diagnosis may have limitations [12]. They suggested these limitations could be overcome by accompanying prehospital ECGs with the patient's clinical history. Similar to McCabe et al., Squire et al. [11] demontrated that using prehospital 12-lead ECGs for STEMI diagnosis did not really reduce the number of false-positive STEMI. De Champlain et al. [9] who used computerized interpretation of the prehospital ECG found a 26% misinterpretation rate for STEMI diagnosis.

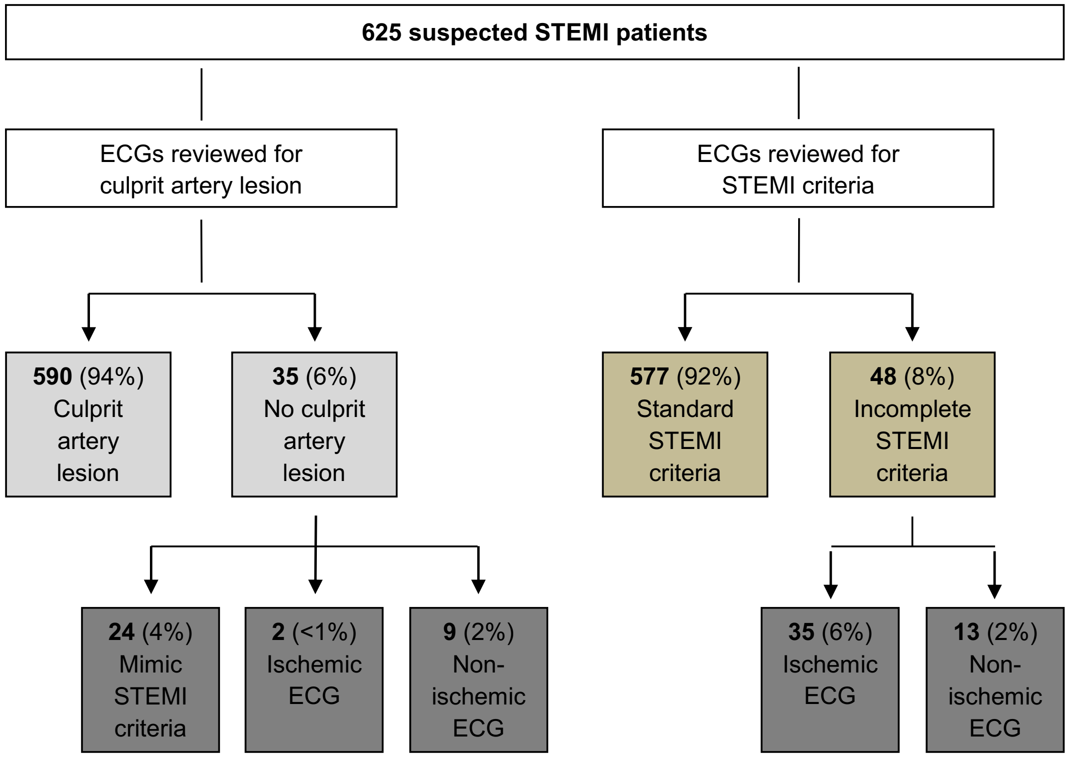

Fig. 2. Diagnostic accuracy of remote ECG interpretation by ED physicians. STEMI = ST-segment elevation myocardial infarction; ECG = electrocardiogram.

The rate of misdiagnosis in our study was 6% when the remote ECG interpretation by the ED physician was compared to results of angiography used as a reference. This is similar to Barge-Carballero et al. [10] and Squire et al. [11] who observed misdiagnosis rates respectively of 7.2% and 7.8% in the prehospital setting. Others have reported higher rates of misdiagnosis in a variety of settings, ranging from 10.0% to 28.7% [13,14,21]. When we compared the ED physician's remote ECG interpretation with our reviewers' reinterpretation based on the 3rd Universal Definition of Myocardial Infarction, the rate of misdiagnosis was 8%. Garvey et al. [22] examined rates of cardiac catheterization cancelation by cardiologists based solely on analysis and reinterpretation of the inciting ECGs in prehospital and ED patients and found that inappropriate activations due to ECG misinterpretation occurred in 10.7% of patients. In our study, patients whose angiographies were cancelled by cardiologists due to disagreement regarding STEMI reinterpretation ($n = 16$) were excluded from analysis. Had we included these patients in our analysis, our misdiagnosis rate as determined by reinterpretation of the inciting ECG by our reviewers would have been 10%, close to the findings of Garvey and colleagues [22].

In our study, misdiagnosed ECGs either mimicked STEMI criteria or had incomplete STEMI criteria (with or without clear ischemic signs). One possible explanation for these misinterpretations is the challenge with identifying a STEMI in ECGs that lack a true STE complex. Studies show physicians have greater difficulty with interpreting ECG patterns such as a subtle STE or QRS repolarization abnormalities that obscure or mimic STE. [3,23] Additionaly, incomplete coronary occlusion are also challenging for STEMI identification [18]. Morever, with remote ECG interpretation, ED physicians cannot perform a physical exam or access previous ECGs, 15-lead ECGs, or other relevant medical records to assist them in making their diagnosis [24]. Another possible explanation is that ED physicians did not adequately evaluate the inciting ECGs for STEMI criteria [1,12,15,17]. Furthermore, some physicians may have overcalled STEMI diagnoses in cases with challenging ECGs in order to err on the side of caution (sensitivity > specificity) and to ensure that the patient received medical attention at the PCI center as quickly as possible [10-14].

We found that misdiagnosis occurred most frequently in patients without any culprit artery lesion on angiography. These patients' ECGs mimicked STEMI criteria and were commonly characterized incorrectly as pericarditis or early ST-segment repolarization. These diagnoses are

Table 2
Final diagnosis in cases without culprit artery lesion where ST-segments imitate STEMI.

Diagnosis	ECGs mimic STEMI criteria, no culprit artery lesion ($n = 24$)
Pericarditis	14 (58)
Early repolarization	7 (29)
Angina	2 (8)
Syncope	1 (4)

STEMI = ST-segment elevation myocardial infarction.
Data are presented as n (%) unless otherwise noted.

Table 3
Characteristics of misinterpreted ECGs with incomplete STEMI criteria.

Characteristic	Ischemic ECG (n = 35)	Non-ischemic ECG ($n = 13$)
STE > 1 mm (1 lead only)	13	0
STE in aVR only	6	0
STE < 1 mm	5	0
ST-segment depression	5	0
Negative T wave	5	0
Non-specific repolarization abnormalities	0	10
LBBB	1	0
Normal ECG	0	3

ECG = electrocardiogram; STE = ST-segment elevation; LBBB = left bundle branch block.

known to be challenging for physicians and often cause ECG misinterpretation [7,25]. This suggests that seeing a depressed PR-segment (except in V1 and aVR) or noting the absence of a ST-segment depression in reciprocal leads were not sufficient to convince ED physicians that the patient did not have a true STEMI. However, when we compared the remote interpretation of ED physicians with those of our reviewers, we found that most patients with incomplete STEMI criteria, had ECGs with ischemic signs characterized by a STE (>1 mm) in only 1 lead, rather than having a STE in 2 or more contiguous leads [1,25]. Furthermore, ED physicians may have believed that cases which mimicked STEMI or had incomplete STEMI criteria could worsen during EMS transport to the point where they satisfied standard STEMI criteria for deviation to the PCI center. For these patients, ED physicians clearly bypassed the AHA standard for STEMI criteria. This reinforces the importance of optimizing the ability of physicians to accurately interpret prehospital ECGs, particularly for challenging ECGs exhibiting complex non-standard STEMI patterns, and to adhere to AHA/ACCF guidelines so the negative effects of overcalling STEMI cases can be avoided.

This study has several limitations. As a retrospective analysis of patient records from the *UCCSPU* and *IUCPQ*, it is subject to the known limitations of retrospective data collection. It is possible that the nursing staff at the OLMC center missed some STEMI cases when interpreting the prehospital ECGs. The use of the 3rd Universal Definition of Myocardial Infarction for the reinterpretation of STEMI ECGs that were diagnosed by ED physicians prior to 2012 and using the 2nd Universal Definition of Myocardial Infarction could create a bias regarding the rate of false positives. However, in our study, and as previously demonstrated in a study by Langorgen et al., employing these two definitions for STEMI did not make a significant difference and had no impact on ECG re-interpretation [26]. Since our study was based on data collected from a single PCI center and a single OLMC center in an EMS system specifically developed for a rural and suburban region of Québec, our results may not be generalizable to other populations, institutions, jurisdictions or EMS systems. Moreover, as the study population was limited to suspected STEMI patients who were diverted to the *IUCPQ* PCI center and received angiography, there exists the possibility of selection bias and our results may therefore underestimate the actual rate of misdiagnosis. Some STEMI patients may not have been included in the study due to ECG misdiagnosis (i.e., false-negative STEMI) by the staff and ED physicians at the OLMC center. Finally, the inciting ECGs used in this study were reviewed by ED physicians in a “no stress context” and the first reviewer was aware of the study objective and patient selection. It is possible that our results would be different had these ECGs been reviewed by cardiologists or another health care specialty, and if both our reviewers had been blinded to the study objective and patient selection.

5. Conclusion

In conclusion, in a regional EMS system that included a remote ECG's interpretation and a direct CCL activation, prehospital 12-lead ECGs of suspected STEMI patients were correctly interpreted by remote ED physicians in 94% of cases compared to angiography results and in 92% of cases compared to ECG reinterpretation based on the 3rd Universal Definition of Myocardial Infarction. Misdiagnosis occurred in cases where ECGs mimicked STEMI criteria such as pericarditis and early repolarization, and where STEMI signs that obscured or mimicked STE were misread. Physicians tasked with remotely interpreting prehospital ECGs must pay more attention to such challenging ECGs in order to minimize negatives consequences and unnecessary health care expenditures. Future efforts to reduce misinterpretation rates should include expanding continuing medical education training to help ED physicians acquire more experience with interpretation of challenging ECGs in suspected STEMI patients.

Acknowledgements

The authors sincerely thank all members of *UCCSPU* and Hôtel-Dieu de Lévis who assisted the research team in accessing records and data, as well as Percipient Research & Consulting for providing assistance with language editing.

All authors have participated in the work and have reviewed and agree with the content of the article. Each author believes that the manuscript represents honest work. Alain Tanguay is the guarantor of this work. He had full access to all of the data, and takes full responsibility for the integrity of the data and the accuracy of the analyses. Alain Tanguay and Johann Lebon performed the literature review, prepared and wrote the manuscript and contributed to the discussion. Johann Lebon collected and analyzed the data. Eric Brassard, François Bégin, Denise Hebert & Alain Tanguay collected the data and reviewed the manuscript and approved the final version submitted.

Funding sources

This work was supported by the *Fondation Hôtel-Dieu de Lévis*, Lévis, Québec, Canada, and has any specific involvement in the present research.

Disclosures

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Contribution

All authors have participated in the work and have reviewed and agreed with the final content of the submitted article. Each author believes that the manuscript represents an honest and original work, not published or reported elsewhere. **Alain Tanguay** is the guarantor of this work, had full access to all of the data, and takes full responsibility for the integrity of the data and the accuracy of the analyses. **Alain Tanguay** and **Johann Lebon** performed the literature review, prepared and wrote the manuscript, and contributed to the discussion. **Johann Lebon** collected and analyzed the data. **Eric Brassard**, **François Bégin** & **Denise Hebert** collected the data, and reviewed the manuscript. All authors approved the final submitted version.

References

[1] O'Gara PT, Kushner FG, Ascheim DD, et al. 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction: executive summary: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines: developed in collaboration with the American College of Emergency Physicians and Society for Cardiovascular Angiography and Interventions. Catheter Cardiovasc Interv 2013;82(1):E1–27.

[2] Amadi-Obi A, Gilligan P, Owens N, et al. Telemedicine in pre-hospital care: a review of telemedicine applications in the pre-hospital environment. Int J Emerg Med 2014; 7:29.

[3] Ting HH, Krumholz HM, Bradley EH, et al. Implementation and integration of prehospital ECGs into systems of care for acute coronary syndrome: a scientific statement from the American Heart Association interdisciplinary council on quality of care and outcomes research, emergency cardiovascular care committee, council on cardiovascular nursing, and council on clinical cardiology. Circulation 2008;118 (10):1066–79.

[4] Davis M, Lewell M, McLeod S, et al. A prospective evaluation of the utility of the prehospital 12-lead electrocardiogram to change patient management in the emergency department. Prehosp Emerg Care 2014;18(1):9–14.

[5] Nam J, Caners K, Bowen JM, et al. Systematic review and meta-analysis of the benefits of out-of-hospital 12-lead ECG and advance notification in ST-segment elevation myocardial infarction patients. Ann Emerg Med 2014;64 (2):176–86.

[6] Ducas RA, Labos C, Allen D, et al. Association of pre-hospital ECG administration with clinical outcomes in ST-segment myocardial infarction: a systematic review and meta-analysis. Can J Cardiol 2016;32(12):1531–41.

[7] Kudenchuk PJ, Maynard C, Cobb LA, et al. Utility of the prehospital electrocardiogram in diagnosing acute coronary syndromes: the Myocardial Infarction Triage and Intervention (MITI) project. J Am Coll Cardiol 1998;32(1):17–27.

[8] Ducas RA, Wassef AW, Jassal DS, et al. To transmit or not to transmit: how good are emergency medical personnel in detecting STEMI in patients with chest pain? Can J Cardiol 2012;28(4):432–7.
[9] de Champlain F, Boothroyd LJ, Vadeboncoeur A, et al. Computerized interpretation of the prehospital electrocardiogram: predictive value for ST segment elevation myocardial infarction and impact on on-scene time. CJEM 2014;16(2):94–105.
[10] Barge-Caballero E, Vazquez-Rodriguez JM, Estevez-Loureiro R, et al. Prevalence, etiology and outcome of catheterization laboratory false alarms in patients with suspected ST-elevation myocardial infarction. Rev Esp Cardiol 2010;63(5):518–27.
[11] Squire BT, Tamayo-Sarver JH, Rashi P, et al. Effect of prehospital cardiac catheterization lab activation on door-to-balloon time, mortality, and false-positive activation. Prehosp Emerg Care 2014;18(1):1–8.
[12] McCabe JM, Armstrong EJ, Ku I, et al. Physician accuracy in interpreting potential ST-segment elevation myocardial infarction electrocardiograms. J Am Heart Assoc 2013;2(5):e000268.
[13] McCabe JM, Armstrong EJ, Kulkarni A, et al. Prevalence and factors associated with false-positive ST-segment elevation myocardial infarction diagnoses at primary percutaneous coronary intervention-capable centers: a report from the activate-SF registry. Arch Intern Med 2012;172(11):864–71.
[14] Larson DM, Menssen KM, Sharkey SW, et al. “False-positive” cardiac catheterization laboratory activation among patients with suspected ST-segment elevation myocardial infarction. JAMA 2007;298(23):2754–60.
[15] Erling BF, Perron AD, Brady WJ. Disagreement in the interpretation of electrocardiographic ST segment elevation: a source of error for emergency physicians? Am J Emerg Med 2004;22(2):65–70.
[16] Thygesen K, Alpert JS, Jaffe AS, et al. Writing group on behalf of the joint ESC/ACCF/AHA/WHF task force for the universal definition of myocardial infarction. Third universal definition of myocardial infarction. Glob Heart 2012;7(4):275–95.
[17] Huitema AA, Zhu T, Alemayehu M, et al. Diagnostic accuracy of ST-segment elevation myocardial infarction by various healthcare providers. Int J Cardiol 2014;177(3):825–9.
[18] Tanguay A, Lebon J, Lau L, et al. Detection of STEMI using prehospital serial 12-lead electrocardiograms. Prehosp Emerg Care 2018:1–8.
[19] Ripa MS. The ECG as decision support in STEMI. Dan Med J 2012;59(3):B4413–.
[20] Verbeek PR, Ryan D, Turner L, et al. Serial prehospital 12-lead electrocardiograms increase identification of ST-segment elevation myocardial infarction. Prehosp Emerg Care 2012;16(1):109–14.
[21] Nfor T, Kostopoulos L, Hashim H, et al. Identifying false-positive ST-elevation myocardial infarction in emergency department patients. J Emerg Med 2012;43(4):561–7.
[22] Garvey JL, Monk L, Granger CB, et al. Rates of cardiac catheterization cancelation for ST-segment elevation myocardial infarction after activation by emergency medical services or emergency physicians: results from the North Carolina Catheterization Laboratory Activation Registry. Circulation 2012;125(2):308–13.
[23] Ayer A, Terkelsen CJ. Difficult ECGs in STEMI: lessons learned from serial sampling of pre- and in-hospital ECGs. J Electrocardiol 2014;47(4):448–58.
[24] Wong CK. Minimizing false activation of cath lab for STEMI–a realistic goal? Int J Cardiol 2014;172(1):e91–3.
[25] Chung SL, Lei MH, Chen CC, et al. Characteristics and prognosis in patients with false-positive ST-elevation myocardial infarction in the ED. Am J Emerg Med 2013;31(5):825–9.
[26] Langorgen J, Ebbing M, Igland J, et al. The universal 2012 definition of myocardial infarction compared to the 2007 definition. Scand Cardiovasc J 2016;50:201–5.