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Assessment of ECG Criteria for the Diagnosis of Right Ventricular Involvement

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ABSTRACT

Objectives: This study was performed to assess the accuracy of standard electrocardiographic criteria in diagnosing of right ventricular (RV) involvement in patients with inferior myocardial infarction (IMI). ***Methods***: This was a retrospective analysis of patients admitted with an IMI. Proximal occlusion of the right coronary artery before the origin of the RV branch on angiography was considered diagnostic of RV involvement. ***Results:*** The subjects were 129 patients (mean age = 55.8±13.1 years; 81.4% male) with inferior ST-elevation myocardial infarction. The most sensitive indicators of RV involvement were an ST elevation in V4R (72.9%) and a higher ST elevation in lead III than in lead II (80.4%). The most specific indicators were ST elevation in V1 (88.7%) and ST elevation in V1 with ST depression in V2 (97.1%). Combining all the criteria improved sensitivity to 85.7% but reduced specificity to 21.2%. ***Conclusions:*** No single electrocardiogram criterion was able to identify all cases of RV involvement in patients with IMI. Combining the different criteria helped pick up more cases at the cost of increasing false positives.

Coronary artery disease is a major cause of morbidity and mortality worldwide, accounting for > 17.5 million deaths annually.[1] They present either as an acute coronary syndrome—such as ST-segment elevation myocardial infarction (STEMI), non-STEMI, and unstable angina—or chronic stable angina (chronic coronary syndromes). STEMI cases are classified based on which aspect of the left ventricular wall is affected. Inferior myocardial infarction (IMI) accounts for around 40–50% of all STEMI.[2] The inferior wall of the heart receives its blood supply through the right coronary artery (RCA) in an estimated 85% of the patients and from the circumflex artery in the remainder.[3] About a third of all instances of acute IMI are associated with right ventricular (RV) infarction.[4] An RV infarction typically occurs when there is an occlusion of the RCA proximal to the point where the RV branch originates, generally located midway along the RCA.

Distal RCA occlusion that does not involve the RV branch results in an isolated IMI. However, not all cases of RV artery occlusion can lead to RV infarction due to the presence of collaterals, multiple small RV branches, or supply from the circumflex.[5] Therefore, we use the term RV involvement rather than RV infarction.

The clinical sequelae of RV involvement vary widely, ranging from asymptomatic to severe hypotension and cardiogenic shock.[6] Research suggests that RV involvement is associated with significant morbidity and mortality. Approximately 50% of such cases are associated with severe hemodynamic and electrical complications.[6,7]

It is important to recognize the presence of RV involvement in patients with IMI because the initial management is different from that of pure left ventricular infarctions.[7] However, the prevalence of such cases appears to be underestimated.[7] The clinical manifestations can include hypotension and clear lung fields with elevated jugular venous pressure. Recognition of RV involvement begins with the identification of the electrocardiogram (ECG) manifestations of inferior wall infarction (ST-segment elevation in leads II, III, and aVF) and the clinical signs of RV involvement. The signs of RV involvement on the standard 12 lead ECG in patients with IMI include ST-segment elevation of > 1 mm in

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lead V1 alone or along with ST-segment depression in lead V2, and higher ST-segment elevation in lead III than in lead II.[8] However, RV involvement can be confirmed by obtaining a right-sided ECG, (placing the chest leads on the right side of the chest corresponding to their original position). The presence of ST-segment elevation of > 1 mm in lead V4R is considered significant and closely correlates with other non-invasive evidence of RV dysfunction in studies quoting > 90% sensitivity.[9,10]

Various ECG signs of RV involvement have reported varying sensitivities, but these are based on studies published decades ago, mostly in the 1980s. The gold standard tests in these studies to identify RV involvement were myocardial perfusion imaging or post-mortem data.[9,11–13] Despite significant advances in diagnostic technologies, there is a dearth of recent evidence based on coronary angiography. Therefore, we aimed to narrow the modern research gap by comparing the diagnostic accuracy of different ECG criteria in identifying proximal RCA occlusion and the RV branch involvement, based on coronary angiography results.

METHODS

In this retrospective case-control study, the subjects were admitted patients diagnosed with IMI at a tertiary teaching hospital in Muscat, Oman. All patients diagnosed with IMI and who underwent primary percutaneous coronary intervention (PCI) between January 2014 and May 2016 were eligible to be included. We excluded patients with true posterior MI and anterior or lateral MI. Ethical approval was obtained from the medical research committee of Sultan Qaboos University (Ref Nos. 1345 and 1351 dated August 30, 2016).

From the electronic patient files, case notes of the eligible patients were reviewed, and the necessary information was obtained. A total of 253 patients had undergone primary PCI for STEMI during the study period. Of these, 139 had IMI and the rest had either anterior wall (n = 112) or isolated lateral wall (n = 2) STEMI. Of those who had documented IMI, 10 patients had missing ECG tracings and were excluded from the study.

The sample size was calculated with an estimated type 1 error of 5%, prevalence of RV involvement of ≈ 33% of all IMI cases, 90% accuracy, and a 10% CI. Using these values, the sample size was determined as 102, but because a few more patients met the selection criteria, we included them as well, raising the actual sample size to 129.

A patient was considered to have an IMI if the ECG showed at least 1 mm ST-segment elevation in two of the three inferior limb leads II, III, and aVf. The ECGs were analyzed for the presence of other anomalies such as conduction abnormalities or arrhythmias. The case notes were also reviewed for clinical presentation. We adopted the established criteria for identifying RV involvement in the presence of IMI, which requires the ECG to have (a) an ST elevation of > 1 mm in V4R, (b) an ST elevation of > 1 mm in lead V1, only or along with ST depression in lead V2, and (c) a higher ST elevation in lead III than in lead II.

Statistical analysis was performed using SPSS Statistics (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.). Data was presented as number (%), mean±SD, or median with interquartile range (IQR). The chi-square test was used to analyze non-parametric data and the student *t*-test for normally distributed data. Sensitivity, specificity, and positive and negative predictive values of the ECG changes were analyzed. Sensitivity was calculated as a ratio of cases where both ECG and angiography were positive, to the total number of angiographic-positive (true positive). Specificity was the ratio of cases where both ECG and angiography were positive, to all angiographic-negative (true negative) cases. The positive predictive value was calculated as a ratio of cases where both ECG and angiography were positive to overall test-positive cases. The negative predictive value was calculated as a ratio of ECG and angiography negative cases, to all ECG negative cases. A p-value < 0.05 was considered significant.

RESULTS

The study subjects were 129 patients diagnosed with inferior STEMI. Their mean age was 55.8±13.1 years, and 105 (81.4%) were male. Their mean systolic blood pressure was 131.2±29.3 mmHg and mean heart rate was 77.3±18.6 beats per minute. The ECG charts of 10 subjects were unavailable. All participants had presented with chest pain with ECG suggestive of inferior STEMI. Most patients presented with one or more comorbidities including diabetes (n = 54), hypertension (n = 76),

Table 1: Comparative mean characteristics of features of patients with and without right ventricular (RV) involvement (N = 129).

Charcteristics	No RV involvement (n = 80) n (%)	RV involvement (n = 49) n (%)	*p*-value
Age, years	55.1 ± 13.6	56.8 ± 12.6	0.490†
Male	66 (82.5)	39 (79.6)	0.680
Female	14 (17.5)	10 (20.4)	
Comorbidities			
Diabetes	34 (42.5)	20 (40.8)	0.920
Hypertension	47 (58.7)	29 (59.2)	0.940
Dyslipidemia	41 (51.2)	27 (55.1)	0.810
Smoker	33 (41.2)	23 (46.9)	0.760
Systolic blood pressure, mmHg	129.3 ± 26.5	134.4 ± 32.9	0.310†
Heart rate, bpm	76.61 ± 16.5	78.4 ± 2.1	0.590†
ECG rhythm change			0.410
AV block	10 (12.5)	9 (18.4)	
RBBB	3 (3.7)	0 (0.0)	
Sinus arrhythmia	4 (5.0)	2 (4.1)	
Atrial fibrillation	1 (1.2)	1 (2.0)	
Junctional rhythm	2 (2.5)	3 (6.1)	
LBBB	0 (0.0)	1 (2.0)	
Associated symptoms			
Breathlessness	21 (26.3)	21 (42.9)	0.050
Syncope	1 (1.3)	7 (14.3)	0.003*
Alive at one year	73 (91.3)	41 (83.7)	0.190

**Significance; bpm: beats per minute; AV: atrio-ventricular; RBBB: right bundle branch block; LBBB: left bundle branch block; †analyzed using student's t-test (all others by chi-square test).*

dyslipidemia (n = 68), smoking habit (n = 56), and syncope (n = 8). Table 1 shows the demographic features of the participants.

All patients were taken up for urgent primary PCI. Based on the angiographic findings, 16 patients had an occluded circumflex artery, and 113 patients had an occluded RCA, of which 49 were occluded proximally before the origin of the RV branch indicating possible RV involvement in 49 (38.0%) cases.

RV involvement was not associated with age, sex, risk factors, hemodynamic features, or the ECG findings of conduction abnormalities or arrhythmias. However, patients with RV involvement were more likely to have breathlessness (42.9% vs. 26.3%; p = 0.050) and syncope (14.3% vs. 1.3%; p = 0.003). Although there was no difference in survival at one year, there was a trend towards higher mortality (91.3% vs. 13.6%; p = 0.190) in patients with RV involvement compared to those without.

Table 2: Electrocardiogram changes in patients with or without right ventricular (RV) involvement (N = 129).

Electrocardiogram	No RV involvement (n = 80) n (%)	RV involvement (n = 49) n (%)	*p*-value
ST elevation in V4R	31 (38.8)	27 (55.1)	0.020*
ST elevation in V1	8 (10.0)	14 (28.6)	0.004*
ST elevation in III > II	60 (75.0)	37 (75.5)	0.220
ST elevation in V1, ST depression in V2	3 (3.8)	8 (16.3)	0.004*
Any of the above	63 (78.8)	42 (85.7)	0.020*

*Analysis by chi-square test. *Significance.*

Table 3: Diagnostic accuracy of the different electrocardiogram (ECG) criteria.

ECG criterion	Sensitivity, %	Specificity, %	Predictive value, %	
			Positive	Negative
ST elevation in V4R	72.9	50.7	46.5	76.1
ST elevation in V1	30.4	88.7	66.3	63.6
ST elevation in III > II	80.4	15.4	55.0	38.0
ST elevation in V1, ST depression in V2	17.3	97.1	63.8	72.7
Any of the above	85.7	21.2	70.8	40.0

Significant ECG differences were observed between the two groups [Table 2]. Patients with RV involvement were more likely to have ST elevation in V4R (55.1% vs. 38.8%; $p = 0.020$), ST elevation in V1 (28.6% vs. 10.0%; $p = 0.004$), and ST elevation in V1 along with ST depression in V2 (16.3% vs. 3.8%; $p = 0.004$). There was no difference between the two groups in terms of higher ST elevation in lead III than in lead II.

Table 3 gives the comparative diagnostic accuracies of various ECG criteria in diagnosing proximal RCA occlusion or RV involvement. ST elevation in V4R and in lead III more than lead II was the most sensitive (72.9% and 80.4%, respectively). However, ST elevation in V4R was an extremely low specificity of 15.4%. (Table 2 shows that it was present in most cases of IMI). ST elevation in V1 by itself and in V1 along with ST depression in V2 had very high specificity of 88.7% and 97.1%, respectively. Combining all the criteria increased sensitivity to 85.7% but reduced specificity to 21.2%.

DISCUSSION

Among the patients with IMI, the incidence of proximal RCA occlusion (and thereby of possible RV involvement) was 38.0%, comparable to previous reports.[4] Patients with RV involvement were more likely to present with breathlessness and syncope. There were no other differences in demography or presentation between the RV and non-RV groups. Due to the lack of documentation in many cases regarding other clinical signs such as jugular venous pressure, pedal edema, or lung signs, we did not include them in our analysis.

The most sensitive ECG criteria for RV involvement in the current study was the presence of a higher ST elevation in lead III. This could be because lead III is more 'rightward facing' than lead II and hence, more sensitive to the injury current produced by the right ventricle.[10,11] ST-segment elevation in the right-sided leads (V4R) was surprisingly absent in almost half of patients with RV involvement. ST elevation in V4R has been previously documented to be a transient event which can disappear after 12 hours in half of the patients.[11,14,15]

The ST elevation in V4R and in lead III > lead II had the highest sensitivity. ST elevation in V1 and in V1 with ST depression in V2 demonstrated the highest specificity. Combining all four studied criteria further increased the sensitivity to 85.7% but at the cost of diminished specificity. Even with all the criteria combined, a few patients still had proximal RCA occlusion but did not have the corresponding ECG changes. Zimetbaum et al,[16] similarly found that a combination of higher ST elevation in lead III than in lead II along with ST elevation in V1 was a strong predictor of proximal RCA occlusion.

One explanation for the low sensitivity and specificity of ECG findings in predicting RV involvement or RV infarction lies in the pathophysiology involved. The RV wall is comparatively thin, leading to changes that are less pronounced than with LV infarctions. During the IMI with RV involvement, the current of injury from the larger inferior LV wall may mask those originating from the infarcted RV.[17] During an inferior or posterior MI, the corresponding parts of the interventricular septum may also get infarcted, showing changes in the RV leads.[8,10,17]

Studies on animals have demonstrated that occlusion of the RV branch can give rise to isolated ST-segment elevation in the right-sided precordial leads (V4R-V6R).[8,18] However, isolated human RV infarcts are extremely rare, as evidenced by the scarcity of published cases.[19,20] Even rarer are reports of isolated RV infarction (where the RV branch of the RCA becomes occluded) incidentally detected during the PCI procedure.[21] In both scenarios, RV infarction has been associated with ST elevation in the precordial leads (V1-V4) along with the right-sided leads (V4R-V6R). The absence of development of Q waves and progressive reduction in the size of the ST elevation in the anterior precordial leads have been suggested as a sign that would help differentiate an anterior MI from an isolated RV infarct.[18,20] Additionally, as mentioned earlier, proximal occlusion of the RCA and thereby occlusion of the RV branch need not always lead to RV infarction. In a minority of patients, the RV may receive blood supply from minor branches, collateral vessels, and branches from the circumflex artery.[5]

Besides the studies mentioned earlier, very few examined ECG findings in RV involvement, and even those are > 30 years old. There were almost no studies during the more recent angioplasty era except for case reports on accidental occlusion of the RV branch during angioplasty. Even in the era of primary angioplasty, early recognition of RV involvement is still important. It should be part of the evaluation of all patients with IMI, especially those who are hypotensive, as the diagnosis would affect decisions on fluid management.[7,22] A quick bedside echocardiogram is recommended to look for signs of potential RV involvement before shifting the patient to the catheter lab for an urgent angiogram if RV involvement is suspected and the ECG is unclear.[23,24] However, in practice, many emergency patients were rushed to the catheter lab for primary angioplasty as soon as they arrived.

This study shared the inherent limitations of retrospective studies, where the quality of data was constrained by the quality of the case note documentation. The hospital files of several participants did not have sufficiently detailed presentation information and clinical examination findings. In some cases, the crucial ECG data was unavailable. This could be due to the emergency nature of many such presentations, resulting in inadequate initial documentation. Similarly, none of our patients had echocardiograms taken before their angioplasty, to reduce the door to balloon time. Pre-procedure echocardiography might have helped in making a diagnosis of RV involvement. We were able to fill in some of the missing data such as demographics and risk factors by contacting the patients directly.

In any case, this study was mainly to assess the effectiveness of the ECG criteria in diagnosing RV branch occlusion (proximal RCA occlusion) and thereby RV involvement. We did not follow up the patients to assess their prognosis related to RV involvement. Additionally, many patients were transferred from regional hospitals managed their follow-up, which made it difficult to obtain follow-up data. Again, this was out of the scope of the study, but older studies, mostly conducted during the late 20th century 'thrombolysis era', have reported poor prognosis in such cases.[6,14,15] It would be worthwhile studying the effects of RV involvement in the modern setting of primary angioplasty, and comparing the prognosis rates in these two periods. This is feasible and would help to further our understanding of RV physiology and its impact on long-term prognosis.

The strength of the study was using angiographic evidence for RV branch involvement to study the diagnostic efficacy of different ECG criteria. In addition, even though the sample size may appear to be low, it was greater than the sample size calculated and therefore the results are valid.

CONCLUSION

No single ECG criteria had shown both high sensitivity and high specificity levels for appropriate electrocardiographic diagnosis of RV involvement in the setting of inferior STEMI. However, ECG, when used with careful evaluation of the clinical signs and symptoms, can guide decision-making in patients with inferior STEMI. It continues to be our most important tool in diagnosing RV involvement and deciding the appropriate treatment strategy.

Disclosure

The authors declared no conflicts of interest. No funding was received for this study.

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