Electrocardiographic identification of the culprit coronary artery in inferior wall ST elevation myocardial infarction

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BACKGROUND: Electrocardiograms (ECGs) are essential in identifying the type and location of acute myocardial infarction. In the setting of inferior wall myocardial infarction (IWMI), identification of the right coronary artery (RCA) as the culprit artery is important because of the potential complications associated with its involvement.

OBJECTIVES: To evaluate previous ECG criteria used for the identification of RCA involvement and validate them in the Assessment of the Safety and Efficacy of a New Treatment Strategy with Percutaneous Coronary Intervention (ASSENT 4 PCI) cohort; and to develop an improved simplified score to identify RCA involvement.

METHODS: ASSENT 4 PCI patients with IWMI (n=710) were included in the present study. A literature review was conducted to identify previously published criteria to detect RCA involvement. Logistic regression was used to develop a new simplified algorithm for identifying RCA involvement.

RESULTS: The sensitivities and specificities of six previous ECG criteria were substantially lower when applied to the ASSENT 4 PCI population. A new algorithm found that ST segment depression in leads I, aVL and V6, and ST segment elevation of greater than 1 mm in lead aVF was associated with a higher likelihood of RCA involvement, and any ST segment depression in V1 and V3 was associated with a lower likelihood of RCA involvement. A simplified risk score found a prevalence of RCA involvement of over 90% among patients with scores of greater than two.

CONCLUSIONS: The ECG is useful in identifying RCA involvement in IWMI before angiography. Previously published criteria appear to be inadequate, and the simple algorithm presented in the current study may be a useful tool in identifying RCA involvement at the bedside.

Key Words: ECG; Inferior wall myocardial infarction; Right coronary artery

Inferior wall ST elevation (ST $\uparrow$) myocardial infarction is caused by right coronary artery (RCA) lesions in approximately 80% of cases. Occlusion of the RCA, especially when involving the right ventricle, may have pronounced hemodynamic complications associated with increased risk of death, shock and arrhythmias (1,2). Management and prevention of these complications may be facilitated by early recognition of RCA involvement.

The importance of electrocardiographic (ECG) changes and their relationship with the infarct-related artery was recognized in the 1980s (3). Several ECG criteria have been proposed to identify the RCA as the culprit artery in inferior wall ST $\uparrow$ myocardial infarction (4-9). However, all the studies to date have reported single-centre experiences involving small sample sizes.

The recent multinational Assessment of the Safety and Efficacy of a New Treatment Strategy with Percutaneous Coronary Intervention

Le dépistage électrocardiographique de l'artère coronaire responsable d'un infarctus de la région inférieure du myocarde avec élévation du segment ST

HISTORIQUE : Les électrocardiogrammes (ECG) sont essentiels pour déterminer le lieu et le foyer des infarctus aigus du myocarde. En cas d'infarctus de la région inférieure du myocarde (IRIM), il est important de repérer l'artère coronaire droite (ACD) responsable, en raison des complications potentielles liées à son rôle.

OBJECTIFS : Évaluer les critères antérieurs d'ECG utilisés pour déterminer le rôle de l'ACD et les valider dans la cohorte ASSENT 4 PCI pour évaluer l'innocuité et l'efficacité d'une nouvelle stratégie thérapeutique pour l'intervention coronaire percutanée et mettre au point un indice simplifié amélioré pour déterminer le rôle de l'ACD.

MÉTHODOLOGIE : Les patients de l'ASSENT 4 PCI ayant un IRIM (n=710) ont participé à la présente étude. Une analyse bibliographique a permis de repérer les critères déterminés auparavant pour déceler le rôle de l'ACD. Les chercheurs ont utilisé la régression logistique pour préparer un nouvel algorithme simplifié afin de repérer le rôle de l'ACD.

RÉSULTATS : La sensibilité et la spécificité des six critères antérieurs d'ECG étaient considérablement plus faibles lorsqu'on les appliquait à la population de l'ASSENT 4 PCI. Un nouvel algorithme a déterminé que la dépression du segment ST dans les dérivations I, aVL et V6 et qu'une élévation du segment ST de plus d'1 mm dans la dérivation aVF s'associaient à une plus forte probabilité que l'ACD y joue un rôle, tandis qu'une dépression du segment ST dans les dérivations V1 et V3 s'associait à une plus faible probabilité que l'ACD y joue un rôle. Un indice de risque simplifié a établi une prévalence de rôle de l'ACD de plus de 90 % chez les patients dont l'indice était supérieur à deux.

CONCLUSIONS : L'ECG est utile pour déterminer le rôle de l'ACD avant l'angiographie en cas d'IRIM. Les critères publiés auparavant semblent inadéquats, et l'algorithme simple employé dans la présente étude pourrait se révéler un outil utile pour déterminer le rôle de l'ACD au chevet du patient.

(ASSENT 4 PCI) trial provided us with a unique opportunity to validate previously identified ECG criteria associated with RCA involvement in an independent, systematically studied patient population undergoing early angiography. In addition to assessing the validity of previously published algorithms, we used the detailed ECG data, evaluated at a central core laboratory, to develop a new algorithm to predict RCA involvement. We then generated a simplified score to enable prediction of RCA involvement at the bedside.

METHODS

Assessment of existing ECG algorithms for RCA involvement

A comprehensive review of the existing literature was conducted to identify studies that had examined ECG criteria associated with RCA involvement. The ECG criteria identified by each of the studies were then applied to the independent ASSENT 4 PCI patient population,

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Figure 1 Flow chart illustrating the selection of patients included in the study. ASSENT 4 PCI Assessment of the Safety and Efficacy of a New Treatment Strategy with Percutaneous Coronary Intervention; IWMI Inferior wall myocardial infarction; LCx Left circumflex artery; MI Myocardial infarction; RCA Right coronary artery

and sensitivities, specificities, positive predictive values (PPVs) and negative predictive values (NPVs) for detecting RCA involvement were calculated for each ECG algorithm.

Patient population

The patient population enrolled in the ASSENT 4 PCI trial has been described previously (10). Briefly, the ASSENT 4 PCI trial enrolled 1667 patients with symptoms of acute myocardial infarction of less than 6 h duration associated with ST $\uparrow$ s of 0.6 mV or greater across multiple leads; for inferior infarction, ST segment deviations of 0.6 mV or greater provided ST $\uparrow$ s of 0.4 mV or greater in leads II, III and aVF; or new left bundle branch block with concordant ST $\uparrow$ of 0.1 mV or greater.

For the purposes of the present study, only those ASSENT 4 PCI patients with inferior wall myocardial infarction (IWMI) were included. A total of 806 IWMI patients were identified (Figure 1). Of these, an additional 96 patients were excluded because they either had a history of myocardial infarction or had missing data. The final study population consisted of 710 patients with IWMI. The identification of the culprit artery was based on a coronary angiogram.

ECG variables

All ECG data were evaluated centrally at the ECG core laboratory at the University of Alberta (Edmonton, Alberta) and at the Duke Clinical Research Institute ECG Core Laboratory (North Carolina, USA). The 12-lead ECGs were recorded at a paper speed of 25 mm/s. ST $\uparrow$ was measured at the J point in an increment of 0.5 mm.

Statistical analysis

Baseline characteristics of patients were expressed as mean $\pm$ SD for continuous variables and as percentages for categorical variables. For the purposes of the analyses, the lead variables were transformed into simplified categorical variables classified according to the extent of ST deviation. Univariate logistic regression was used to examine the association between each ECG lead and RCA involvement. All leads found to be associated with RCA involvement at $P \leq 0.20$ were included in a backward stepwise logistic regression model. The overall performance of the model was assessed using the c-index.

A simplified score to identify RCA involvement was developed by assigning a weight corresponding to the beta-coefficient (rounded to the nearest whole number) associated with the extent of ST deviation in each lead in the multivariable model. The score was used to categorize patients into three groups (low, medium or high) based on their likelihood of RCA involvement. The prevalence of RCA

TABLE 1
Previously published criteria to determine right coronary artery involvement in the setting of inferior wall myocardial infarction

Reference(s)	Criteria	Sample size, n	SN, %	SP, %
Herz et al (8), Fiol et al (9), Gupta et al (5)	ST $\uparrow$ III > II	83 63 104	88 88 99	94 69 100
Herz et al (8)	ST $\downarrow$ aVL > I	83	80	94
Fiol et al (9)	ST $\downarrow$ I	63	92	77
Fiol et al (9)	(sum ST $\downarrow$ V1-3) / (sum ST $\uparrow$ inf) ≤ 1	63	94	61
Prieto-Solis (6), Prieto-Solis et al (4)	Arth sum ST segment: aVF+V2 > 0	100 66	100 100	100 100
Kosuge et al (7)	ST $\downarrow$ V3/ST $\uparrow$ III ≤ 1.2	152	84	93

Arth Arithmetic; inf Inferior; SN Sensitivity; SP Specificity; ST $\uparrow$ ST segment elevation; ST $\downarrow$ ST segment depression

involvement, as well as other clinically relevant complications such as hypotension and right heart failure, was examined across the three groups to determine the accuracy of the score. All statistical analyses were performed using SPSS version 14 (SPSS Inc, USA).

RESULTS

Based on a comprehensive review of the literature, six studies that had previously identified ECG criteria associated with RCA involvement in IWMI were found (Table 1). These studies were all single-centre experiences and involved small sample sizes (range $n=63$ to $n=152$). The sensitivities and specificities reported for each of the ECG algorithms ranged from 84% to 100% and from 61% to 100%, respectively.

The mean ($\pm$ SD) age of the 710 patients in ASSENT 4 PCI with IWMI was 59.7 ± 11.7 years, and 76% ($n=539$) were men. Forty-two per cent of the patients had a medical history of hypertension and 15% had a history of diabetes. The RCA, as identified by the site investigator, was the main culprit artery in 539 (76%) patients. Thirty-day mortality was significantly lower among RCA patients (1.9%) compared with patients with an infarct in the left circumflex artery (5.4%, $P=0.04$).

The results of using each of the six ECG algorithms to assess RCA involvement in the ASSENT 4 PCI patients are provided in Table 2. The analysis showed that the best criteria to identify RCA as the culprit artery in IWMI were ST $\uparrow$ in lead III greater than in lead II (86% sensitivity, 52% specificity, 86% PPV and 53% NPV), and ST $\downarrow$ in lead I (84% sensitivity, 60% specificity, 87% PPV and 53% NPV).

The second objective of the present study was to develop a new algorithm for RCA involvement using the large cohort of patients enrolled in the ASSENT 4 PCI trial. First, the univariate associations between ST deviation in each lead and RCA involvement in the ASSENT 4 PCI population were examined. ST $\downarrow$ in leads I, aVL, V5 and V6, and ST $\uparrow$ in leads III and aVF were associated with a higher likelihood of RCA involvement. In contrast, ST $\downarrow$ in leads aVR, V1 and V3 was associated with a higher likelihood that RCA was not involved. In multivariable analyses, ST $\downarrow$ in leads I, aVL and V6, and ST $\uparrow$ in lead aVF was associated with a higher likelihood of RCA involvement (Figure 2). The presence of ST $\downarrow$ in leads V1 and V3 was associated with a lower likelihood of RCA involvement. The model's c-index (ie, its ability to discriminate RCA involvement) was very good at 0.82.

Table 3 shows the simplified RCA score that is based on the present study's multivariable model. The RCA score for the ASSENT 4 PCI population ranged from -2 to 5 . Patients were categorized into three groups: low (RCA score of 0 or lower), medium (RCA score of 1 or 2), and high (RCA score of greater than 2). The prevalence of RCA

TABLE 2
Sensitivities and specificities associated with each previously identified criteria to detect right coronary artery involvement when applied to the Assessment of the Safety and Efficacy of a New Treatment Strategy with Percutaneous Coronary Intervention (ASSENT 4 PCI) population (n=710)

Criteria	SN, %	SP, %	PPV, %	NPV, %	c-index
ST↑ III > II	86	52	86	53	0.69
ST↓ aVL > I	85	28	79	37	0.66
ST↓ I	84	60	87	53	0.70
(sum ST↓ V1-3)/(sum ST↑ inf) ≤1	90	28	79	48	0.64
Arth sum ST segment: aVF+V2 >0	69	49	82	32	0.57
ST↓V3/ST↑III ≤1.2	91	32	79	55	0.67

Arth Arithmetic; inf Inferior; NPV Negative predictive value; PPV Positive predictive value; SN Sensitivity; SP Specificity; ST↑ ST segment elevation; ST↓ ST segment depression

Figure 2) Multivariable predictors of right coronary artery (RCA) involvement (c-index = 0.82). ST↑ ST segment elevation; ST↓ ST segment depression

involvement and relevant clinical complications during the index hospitalization in the three groups of patients is presented in Figure 3 and Table 4, respectively. Increasing score was significantly associated with higher rates of RCA involvement ($P < 0.01$). Patients with a score of greater than 2 had more than a 90% chance of RCA being the culprit artery. Rates of hypotension and right heart failure were also significantly higher among patients with higher RCA scores.

DISCUSSION

Although coronary angiography is the gold standard for determining the infarct-related artery in acute myocardial infarction, the ECG can be a useful tool in identifying which artery is involved at the first point of care. Differentiating RCA involvement from left circumflex coronary artery involvement may also be clinically relevant in risk stratifying patients with IWMI. A previous study (11) showed that patients with an infarct in the left circumflex coronary artery have worse outcomes than patients with infarcts in the RCA. The present data support these findings: the 30-day mortality rate in the ASSENT 4 IWMI population was significantly higher among patients with an infarct in the left circumflex distribution.

Previous studies examining ECG criteria to identify RCA involvement in IWMI have all been single-centre studies with small sample sizes. The present study examined the validity of previously established

TABLE 3
Nomogram to calculate right coronary artery score

Lead	Value	Points
aVF	ST↑ >1 mm	1
aVL	ST↓ >1 mm	1
I	Any ST↓	2
V6	Any ST↓	1
V1	Any ST↓	-1
V3	Any ST↓	-1

ST↑ ST segment elevation; ST↓ ST segment depression

Figure 3) Distribution of right coronary artery (RCA) score in inferior wall myocardial infarction

TABLE 4
Frequency of complications by right coronary artery (RCA) score

Outcome	RCA score			P
	Low (≤0)	Medium (1 or 2)	High (>2)	
Hypotension	1.8	1.6	4.8	0.05
Right heart failure	0.0	0.0	2.4	<0.01
Congestive heart failure	4.8	5.6	5.2	0.95
Shock	1.8	3.2	3.5	0.60
Bradycardia	3.0	5.2	4.8	0.53

ECG algorithms in an independent patient population, namely patients enrolled in the ASSENT 4 PCI trial. In addition to the advantage of a large sample size (710 patients) enrolled in 24 countries, the ECGs in the ASSENT 4 PCI trial were assessed centrally at a core laboratory facility, thereby ensuring standardized evaluation and interpretation.

The sensitivities and specificities associated with previous ECG criteria, when applied to the independent ASSENT 4 PCI population, were significantly lower than those observed in the populations in which they were developed. Among the six criteria identified previously, an ST↓V3/ST↑III of 1.2 or lower had the highest sensitivity (91%) but was associated with an extremely low specificity (32%). The criteria that maximized both sensitivity and specificity were ST↑ in lead III greater than that in lead II, which can probably be attributed to the fact that in RCA involvement, the ST segment vector is directed toward the right (lead III); and ST↓ in lead I, which represents the reciprocal changes for the area supplied by the RCA. The added finding of ST↑ in lead V1 suggests proximal occlusion of the RCA with associated right ventricular infarction. Conversely,

infarction involving the left circumflex artery produces an ST segment vector directed toward the left (lead II). In this case, ST $\uparrow$ in lead III is not greater than that in lead II, and there is an isoelectric or elevated ST segment in lead aVL, ST $\downarrow$ in leads V1 and V2, with ST $\uparrow$ in the inferior leads also suggesting involvement of the left circumflex vessel, but the pattern may also be seen in infarction caused by occlusion of a dominant RCA. In either circumstance, ST $\downarrow$ in leads V1 and V2 suggest concomitant infarction of the posterior wall of the left ventricle (12). Although these criteria performed better relative to the other criteria, their ability to discriminate RCA involvement as measured by the c-index was mediocre (0.69 and 0.70, respectively). We, therefore, used multivariable logistic regression analysis to develop a new ECG algorithm using the ASSENT 4 PCI data. We found that any ST $\downarrow$ in leads I, aVL and V6, and any ST $\uparrow$ in lead aVF was associated with a higher likelihood of RCA involvement. In contrast, ST $\downarrow$ in leads V1 and V3 was associated with a lower likelihood of RCA involvement. The model's c-index was very good at 0.82. We used the results of the multivariable model to generate a simplified risk score to identify RCA involvement at the bedside. Risk scores of greater than 2 were associated with a greater than 90% probability of RCA involvement and a higher frequency of complications such as hypotension and right heart failure. Given the simplicity of the score, it can be easily incorporated into ECG machines and personal digital assistants.

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Limitations

Our study has some limitations. First is the lack of information regarding the right precordial leads (particularly V4R), which have an established role in determining RCA as the culprit artery in IWMI (2). Also, our database lacks information about Q waves, U waves and QRS morphology that has previously been used to differentiate the RCA from the left circumflex artery as the culprit artery in IWMI (13-15).

CONCLUSION

Although coronary angiography remains the gold standard method for determining the infarct-related artery in acute myocardial infarction, ECG information can help to anticipate which artery is involved before angiography, especially in hospitals without onsite angiographic facilities. Previously published criteria, developed based on small groups of patients, appear to be inadequate in identifying RCA involvement. Our simple algorithm, generated from a large cohort of patients, may be a useful tool in identifying RCA involvement at the bedside.

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