Received: 3 April 2019 | Revised: 23 April 2019 | Accepted: 8 May 2019

DOI: 10.1002/joa3.12196

ORIGINAL ARTICLE

WILEY Journal of Arrhythmia Open Access

Electrocardiographic early repolarization is associated with future ventricular arrhythmia after acute myocardial infarction—Systematic Review and Meta-Analysis

Raymond Pranata MD[1] | Emir Yonas MD[2] | Rachel Vania MD[1] | Sunu Budhi Raharjo MD, PhD[3] | Bambang Budi Siswanto MD, PhD, FAPSC, FIHA[3] | Budhi Setianto MD, PhD[3]

[1]Faculty of Medicine, Universitas Pelita Harapan, Tangerang, Indonesia

[2]Faculty of Medicine, Universitas YARSI, Jakarta, Indonesia

[3]Department of Cardiology and Vascular Medicine, Faculty of Medicine Universitas Indonesia, National Cardiovascular Center Harapan Kita, Jakarta, Indonesia

Correspondence
Raymond Pranata, Faculty of Medicine, Universitas Pelita Harapan, Tangerang, Banten, Indonesia.
Email: raymond_pranata@hotmail.com

Abstract

Background: Early repolarization (ER) has been linked to ventricular arrhythmia (VA) and sudden cardiac death in patients without structural heart disease. We aimed to assess the latest evidence on whether ER is associated with future VA after acute myocardial infarction (AMI).

Methods: We performed a comprehensive search on the topic that assesses ER and VA/adverse cardiovascular events in AMI. We included studies with sufficient details on ER and VA, we also performed a meta-analysis on their morphology.

Results: A total of 3350 subjects from 9 studies were included. Five hundred and twenty-one (15.55%) had ER and 2829 (84.45%) did not. On meta-analysis, ER (+) in AMI was associated with VA with a pooled odds ratio (OR) of 3.58 (2.70-4.73), $P < 0.001$; heterogeneity I^2 34%. Subgroup analysis of patients with ST-segment elevation myocardial infarction (STEMI) showed an OR of 2.79 [1.98-3.93], $P < 0.001$; heterogeneity I^2 0%. Inferior location of ER (+) was associated with VA OR 3.98 [1.86-8.53], $P = 0.008$; I^2 67%. Notching had a 5.41 [3.52-8.32], $P < 0.001$; low heterogeneity I^2 0% of having VA. Pooled OR for J-point elevation was 4.72 [2.63-8.46], $P < 0.001$; I^2 25%. Horizontal ST-segment was associated with VA with an OR of 4.30 [1.89-975], $P < 0.001$; I^2 59%. Lateral location and slurred morphology were not associated with VA. Upon sensitivity analysis for inferior location and horizontal ST-segment, removal of a study reduces heterogeneity significantly.

Conclusion: Early repolarization especially those with the inferior location, notching morphology, an elevated J-point and horizontal ST-segment had a higher likelihood of VA in AMI including STEMI patients.

KEYWORDS

acute myocardial infarction, early repolarization, ST-segment elevation myocardial infarction, ventricular arrhythmia

1 | INTRODUCTION

Early repolarization (ER) is a common electrocardiographic (ECG) finding defined as (a) presence of end-QRS notch or slur on the downslope of a prominent R-wave. If there is a notch, it should lie entirely above the baseline. (b) The onset of a slur must also be above the baseline. J peak is ≥0.1 mV in 2 or more contiguous leads of the 12-lead ECG, excluding leads V1-V3; and (c) QRS duration is <120 ms.[1] ER can be found in 1%-5% of the population.[2,3] It was once regarded as a benign variant in young and healthy subjects, was recently found to cause ventricular arrhythmia (VA) and sudden cardiac death in patients without structural heart disease in specific subtypes.[4–8] It was also associated with a higher risk of ventricular arrhythmias in chronic coronary artery disease.[9]

We aimed to assess the latest evidence on whether ER is associated with future ventricular arrhythmia after acute myocardial infarction. We also aimed to analyze the characteristics of ER that are associated with VA in AMI patients, since only specific type of ER is found to be malignant in those without structural heart disease and whether ER also applies in ST-segment elevation myocardial infarction (STEMI) patients exclusively.

2 | METHODS

2.1 | Search strategy

We performed a comprehensive search on topic that assesses ER and VA/adverse cardiovascular events in AMI with keywords ["Early Repolarization" and "myocardial infarction"] and its synonym from inception up until February 2019 through PubMed, EuropePMC (non-MEDLINE), EBSCOhost (non-MEDLINE), Cochrane Central Database, ClinicalTrials.gov, and hand sampling from potential articles cited by other studies. The records were then systematically evaluated using inclusion and exclusion criteria. We also perform hand sampling from references of the included studies. Two researchers (E.Y and R.V) independently performed an initial search, discrepancies were resolved by discussion. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart of the literature search strategy of studies was presented in Figure 1.

2.2 | Selection criteria

The inclusion criteria for this study are all studies that assess ER and VA/adverse cardiovascular events in AMI. Ventricular arrhythmias in our study are defined as VT/VF. We include all related clinical researches/original articles and exclude case reports, review articles, and non-English language articles.

2.3 | Data extraction

Data extraction and quality assessment was done by 2 independent authors (R.P and E.Y) using standardized extraction form which includes authors, year of publication, study design, sample size, timing of ECG, study definition of VA, presence of early repolarization, location of ER, Notched or slurred morphology, ST-segment morphology, J-point elevation, and follow-up period.

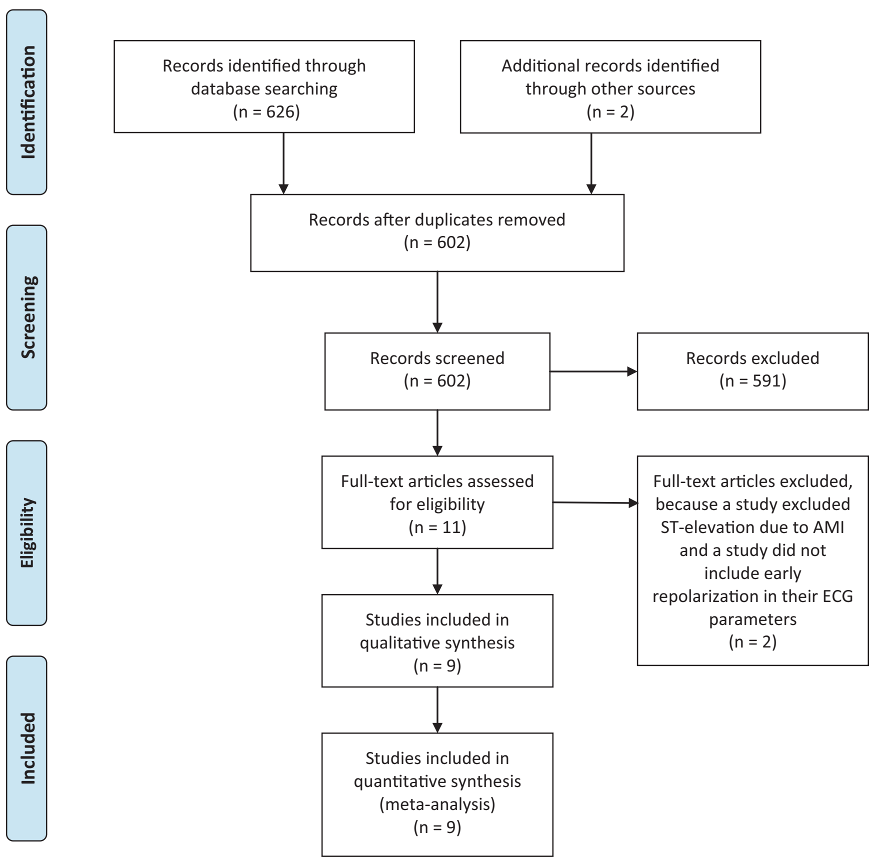

FIGURE 1 Study flow diagram

TABLE 1 Summary of the key findings of this systematic review

Study	Design	Patients Included	Samples (n)	ECG for ER	ER (+) (n)	Study Definition of VA	VA [ER (+)/ER (-)]
Chen 2017	Retrospective Observational	Acute Anterior STEMI	654	24 h after AMI diagnosis	183 (27.9%)	VT/VF	19% vs 22%, *P* = 0.007
Diab 2014	Prospective Observational	Acute STEMI (Male only)	102	Before AMI after resolution, or leads unrelated to AMI	42 (41.2%)	VT/VF	55.7% vs 28% *P* = 0.008
Kim 2014	Retrospective Observational	AMI	296	Before AMI	52 (17.6%)	VF	59% vs 14.2%, *P* < 0.001
Naruse 2012	Retrospective Observational	AMI	220	Before AMI	34 (16%)	VF	48% vs 12% *P* < 0.001
Naruse-2 2014	Retrospective Observational	AMI	1131	Day 10 of AMI	99 (9%)	VT/VF/SD	31% vs 8% *P* = 0.001
Ozcan 2014	Prospective Observational	Acute STEMI	521	Before AMI	61 (11.7%)	VT/VF	19.6% vs 10.9% *P* = 0.04
Park 2014	Retrospective Observational	Acute STEMI undergoing pPCI	266	Day 2 of AMI	76 (28.6%)	VT/VF	79% vs 92% *P* = 0.004
Patel 2012	Retrospective Observational	Acute STEMI	100	Before AMI	50 (50%)	nsVT/VT/VF	26% vs 4% OR = 6.5 (1.5-28.8) *P* = 0.01
Rudic 2012	Prospective Observational	AMI	296	Day 5 of AMI	30 (50%)	VF	47% vs 13% OR = 5.7 (1.4-22.0) *P* = 0.01

Abbreviations: AMI, Acute Myocardial Infarction; ER, Early Repolarization; N/A, Not Available/Applicable; nsVT, Non-sustained Ventricular Tachycardia; OR, Odds Ratio (95% Confidence Interval); pPCI, Primary Percutaneous Coronary Intervention; SD, Sudden Death; STEMI, ST-Segment Myocardial Infarction; VA, Ventricular Arrhythmia; VF, Ventricular Fibrillation; VT, Ventricular Tachycardia.

2.4 | Statistical analysis

To perform the meta-analysis, we used RevMan version 5.3 software (Cochrane Collaboration) and STATA 14. We used the odds ratio (OR) and a 95% CI as a pooled measure for dichotomous data. We used mean difference (MD) and its SD as a pooled measure for the continuous data. Inconsistency index (I^2) test which ranges from 0% to 100% was used to assess heterogeneity across studies. A value above 50% or $P < 0.05$ indicates statistically significant heterogeneity. We used the Mantel-Haenzsel method (for OR), and the Inverse Variance method (for MD) with a fixed effect model for meta-analysis and a random effect model was used in case of heterogeneity. All P values were 2-tailed with a statistical significance set at 0.05 or below.

3 | RESULTS

We found a total of 626 results and acquired 2 additional records from hand sampling from related citations. There were 602 records after removal of duplicates. After screening the title/abstracts, 591 records were excluded. After assessing 11 full-text for eligibility; we excluded 2 because of unrelated outcomes. Shulman et al only included ST-segment elevation in general and excluded AMI patients. Yu et al did not include early repolarization in their ECG parameters. We included 9 studies in the qualitative synthesis and meta-analysis.[10–18] (Figure 1) Three studies were prospective observational studies and 6 studies were retrospective observational. There were a total of 3350 subjects from 9 studies. (Table 1).

3.1 | Study characteristics

A total of 3350 subjects from 9 studies were included. Five studies included patients with STEMI, and 2 studies included AMI patients in general. Five hundred and twenty-one (15.55%) had ER and 2829 (84.45%) did not. Nine studies included VT and/or VF as their VA outcome. Two studies added additional criteria for VA outcome, Patel et al included non-sustained VT (nsVT) as in their VA outcome and Naruse et al[10,13] included sudden death in theirs. Five studies analyze the association between the location of ER on ECG and VA.

VA (Location of ER)	VA [Slurred (+)/ (-)]	VA [Notch (+)/ (-)]	VA [Horizontal ST-segment/ others]	VA and J-Point elevation	Follow-up (mean, months)
Inferior: 78.94% vs 82.31% *P* = 0.963	45.73% vs 21.05% *P* = 0.07	68.42% vs 47.56% *P* = 0.139	89.47% /89.02% *P* = 0.742	21.05% vs 15.85% *P* = 0.801	15
Lateral: 13.4% vs 8% *P* = 0.52 Inferior/Inferolateral: 28.8% vs 18% *P* = 0.29 Global: 13.4% vs 2% *P* = 0.06	11.5% vs 16% *P* = 0.71	44.2% vs 12% *P* = 0.0007	53.8% vs 24% *P* = 0.003	N/A	N/A
Inferior: 50% vs 7.2% *P* < 0.001	4.5% vs 3.6% *P* = 0.999	54.5% vs 10.6% *P* < 0.001	N/A	9% vs 0.7% *P* = 0.029	N/A
Inferior: 38% vs 9% *P* = 0.001	10% vs 3% *P* = 0.171	38% vs 9% *P* = 0.001	43% vs 8% *P* < 0.001	29% vs 6% *P* = 0.002	N/A
Inferior: 27% vs 6% *P* = 0.001 Lateral: 0% vs 2% *P* = 1.000, Inferior and Lateral: 4% vs 1% *P* = 0.170	8% vs 2% *P* = 0.126	23% vs 6% *P* = 0.004	0% vs 3% *P* = 1.000	12% vs 2% *P* = 0.027	26.2
N/A	N/A	N/A	N/A	N/A	21
N/A	N/A	N/A	N/A	N/A	30.6 ± 16.4
Anterior: 16% vs 0% *P* = 0.01 Inferior ER 14% vs 2% *P* = 0.07	6% vs 2% *P* = 0.34	10% vs 2% *P* = 0.1	N/A	16% vs 0%. (No p value available)	12
Lateral ER 17% vs 3%; OR = 5.6 (0.4-41.8) *P* = 0.2 Inferior ER 17% vs 7%; OR = 3.1 (0.5-18.8) *P* = 0.2, Inferolateral ER 13% vs 3%; OR 5.2 (0.5-58.7) *P* = 0.2	7% vs 7% OR 0.5 (0.05-5.7) *P* = 0.6	40% vs 7%; OR 10.2 (1.9-55.8) *P* = 0.007	N/A	27% vs 7%, OR:6.2 95CI (1.1-35.1) *P* = 0.04	N/A

Five studies reported the morphological characteristics of ER and their association with VA.

3.2 | Early repolarization and ventricular arrhythmia

Nine studies showed that ER was associated with VA in patients with AMI.[10–18] On meta-analysis, ER (+) was associated with VA with a pooled OR of 3.58 (2.70-4.73), $P < 0.001$; heterogeneity I^2 34%, $P = 0.15$. Pooled sensitivity 41.1%, specificity 84.2%, LR (+) 2.6, and LR (−) 0.69. (Figure 2A).

Patel et al included non-sustained VT as VA outcome in addition to VT/VF, upon removal of their study, the OR was 3.41 [2.56-4.54], $P < 0.001$; heterogeneity I^2 36%, $P = 0.14$. Pooled sensitivity 36%, specificity 86%, LR (+) 2.66, and LR (−) 0.73.

Subgroup analysis of STEMI patients from 5 studies showed an OR of 2.79 [1.98-3.93], $P < 0.001$; heterogeneity I^2 0%, $P = 0.52$. Upon removal of Patel et al study the OR was 2.54 [1.78-3.63], $P < 0.001$; heterogeneity I^2 0%, $P = 0.82$. Pooled sensitivity 52.4%, specificity 72.8%, LR (+) 1.93, and LR (−) 0.65. (Figure 2B).

3.3 | Early repolarization and mortality

Ozcan et al reported that ER (+) was associated with increased mortality with an OR of 3.48 [1.28-0.41]; $P = 0.014$ at 30 days and increased mortality OR 3.28 [1.31-8.20]; $P = 0.011$ at mean 1.75 years' follow-up.[15] However, Chen et al[11] reported non-significant mortality at 30 days. Both Ozcan et al and Chen et al reported a non-significant difference in major adverse cardiovascular events (MACE).

3.4 | Characteristics of early repolarization associated with ventricular arrhythmias

3.4.1 | Location of early repolarization on ECG

Three studies reported that the inferior location of ER was associated with VA.[13,14,17] Four studies showed no significant association.[11,12,15,18] The pooled analysis showed that inferior location of ER was significantly associated with VA with an OR of 3.98 [1.86-8.53], $P = 0.008$; I^2 67%, $P = 0.006$. Pooled sensitivity 38.4%, specificity 86%, LR (+) 2.74, and LR (−) 0.72. (Figure 3A). Lateral and global/both location of ER was not associated with a higher VA incidence.

3.4.2 | Morphology of early repolarization

Five studies reported that notching of J-Wave in ER (+) patients had a statistically significant relation with VA incidence.[12–14,18] Two studies reported a higher incidence of VA in notching, however, they were not statistically significant.[10,11] On pooled analysis of these 7 studies, notching had an OR of 5.41 [3.52-8.32], $P < 0.001$; low heterogeneity I^2 0%, $P = 0.70$ of having VA. Pooled sensitivity 45.2%, specificity 87.7%, LR (+) 3.68, and LR (−) 0.62. (Figure 3B) Slurred J-Wave morphology was not associated with VA.

Four studies showed that J-point elevation was more frequent in VA groups and 2 studies demonstrated no difference. Five studies used ≥0.2 mV as their cut-off for J-point elevation, but Patel et al also added a different cut-off for women. Rudic et al did not explicitly stated the cut-off point. A pooled OR was 4.72 [2.63-8.46], $P < 0.001$; I^2 25%, $P = 0.24$ for J-point elevation. Pooled sensitivity 44.7%, specificity 87.8%, LR (+) 5.8, and LR (−) 0.63. (Figure 3C).

Three studies reported that horizontal ST-segment in ER (+) patients were associated with a higher incidence of VA and one study did not.[11–14] Pooled OR showed that horizontal ST-segment was associated with VA with an OR of 4.30 [1.89-975], $P < 0.001$; I^2 59%; $P = 0.06$. (Figure 3D) Naruse (2012) et al combined horizontal with descending, after removal of the study, the result was still significant. Upsloping ST-segment was not related to increased VA.

We performed a sensitivity analysis for the pooled result with moderate-high heterogeneity (inferior location and horizontal ST-segment) by removing study one at a time. Upon removal of Chen et al study for the inferior location of ER and the use of the fixed-effect model, the pooled result became OR 4.66 [2.90-7.47], $P < 0.001$; heterogeneity I^2 46%, $P = 0.10$. Removal of Chen et al study in the analysis for horizontal ST-segment and the use of the fixed effect model resulted in OR 5.08 [2.85-9.06], $P < 0.001$; low heterogeneity I^2 31%, $P = 0.23$. Hence, both results are still significant with a higher pooled OR and lower heterogeneity.

We performed a subgroup analysis on studies that exclusively assessed ECG before AMI event. Pooled OR for ER and VA was 5.11 [2.27-11.53], $P < 0.001$; heterogeneity I^2 64%, $P = 0.04$. Pooled OR for inferior ER and VA was 8.70 [4.37-17.30], $P < 0.001$; heterogeneity I^2 0%, $P = 0.59$. Pooled OR for notching of J-wave and VA was 7.61 [3.88-14.89], $P < 0.001$; heterogeneity I^2 0%, $P = 0.73$. As for the J-point elevation was 9.74 [3.26-29.15], $P < 0.001$; heterogeneity I^2 0%, $P = 0.43$.

4 | DISCUSSION

Early repolarization was associated with the incidence of VA in AMI and STEMI patients. Inferior location of ER on ECG, notching of J-Wave, J-point elevation, and horizontal ST-segment are associated with an increased risk of VA. Inferior location of ER and horizontal ST-segment depression had a high heterogeneity that drops drastically after removal of a study, and the result remained significant after the omission. Increased risk of VA in notched J-waves is similar to ER in general, in which QRS notching was associated with VT/VF.[19] Most of these finding had specificity >80% and can be useful for ruling in. Most of the studies did not measure electrolytes that may affect ST-T segment. Patel et al and Rudic et al also had a small event in patients without ER because of a 50%-50% distribution of cases and controls. One of the major issues is that the timing of ECG differs from one study to another, there were studies that assess the ER prior to AMI, during hospitalization (using leads unrelated to AMI) or after AMI (after ST-segment resolution) or any. Acute ischemia may confound the finding of J-point elevation, however, most of these studies assessed ER before AMI or after the resolution of ST-segment changes; 2 studies did assess during acute ischemia, however, it only assesses ER in leads that are unrelated to the events. Furthermore, upon subgroup analysis, these parameters were significantly still significant for VA including that of J-point elevation. Most of the studies also did not report the length of hospitalization during AMI, varying duration may affect the outcome.

Diab et al only evaluated male patients with STEMI and had similar results to the other studies; however, their study reported a non-significant difference between the inferior location of ER and VA. This incites a possibility that inferior location of ER might have more significant effect on VA risk in female rather than male (gender role) and we recommend the addition of gender on the analysis of ER location and VA on further investigation.

A study by Chen et al only assessed the outcome in anterior STEMI patients and may have a different result to the other studies that included all location of AMI. Anterior STEMI is known to have a higher VF risk, although we did not know whether ER will affect this risk differently.[14,20] Chen et al also shown a different baseline characteristic of those with ER and without regarding acute PCI, a higher percentage of PCI can be found on those with ER. This may reduce the incidence of arrhythmia may explain for certain non-significant finding such as inferior location, notched J wave, and horizontal ST-segment that was usually found to be associated with VA in other studies.

Naruse et al and Patel et al added measure that differs from the other studies as their VA outcome that being sudden death and non-sustained VT on each mentioned studies, respectively. This may lead to overestimation of our outcome of interest related to ER. Especially on Patel et al study in which most of the events (78%) are non-sustained VT; this may not represent our outcome of interest. Patel et al study also have a limited number of events (two) in ER (−), it is also not clearly defined as VT/VF/non sustained VT which may result in a different interpretation of the result. Patel et al study also had a broad range of confidence interval and did not include the difference between ER morphological characteristics.

Kim et al and Naruse et al measured VF as their only outcome. This may underestimate our outcome of interest related to ER which

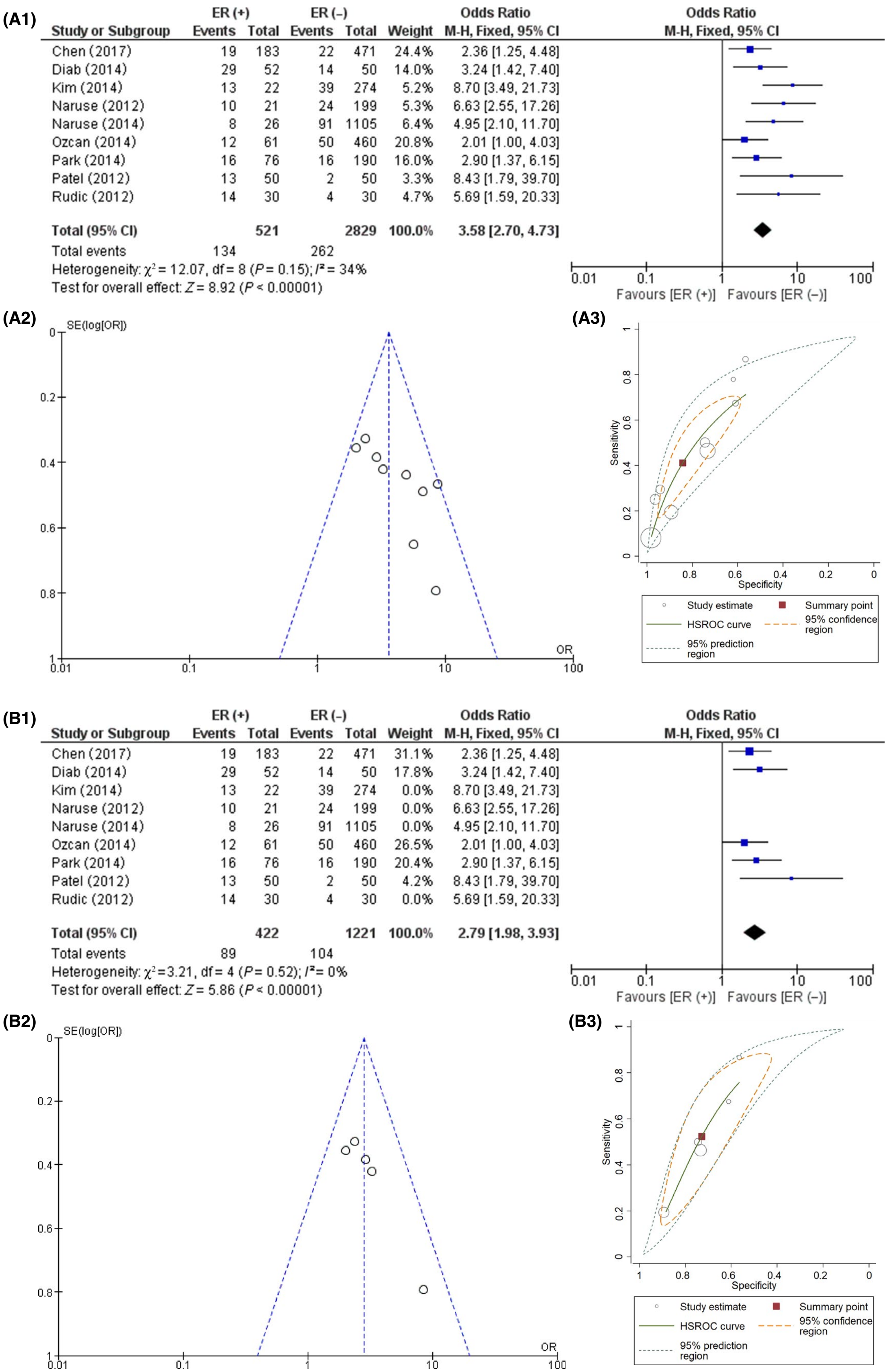

FIGURE 2 Pooled analysis of association between early repolarization and ventricular arrhythmias. The presence of ER is associated with the incidence of VA (A). (B), showed a subgroup analysis on patients with STEMI, ER was significantly associated with VA in this subgroup. Description: ER, Early Repolarization; nsVT, Non-sustained Ventricular Tachycardia; STEMI, ST-segment Elevation Myocardial Infarction;VA, Ventricular Arrhythmia

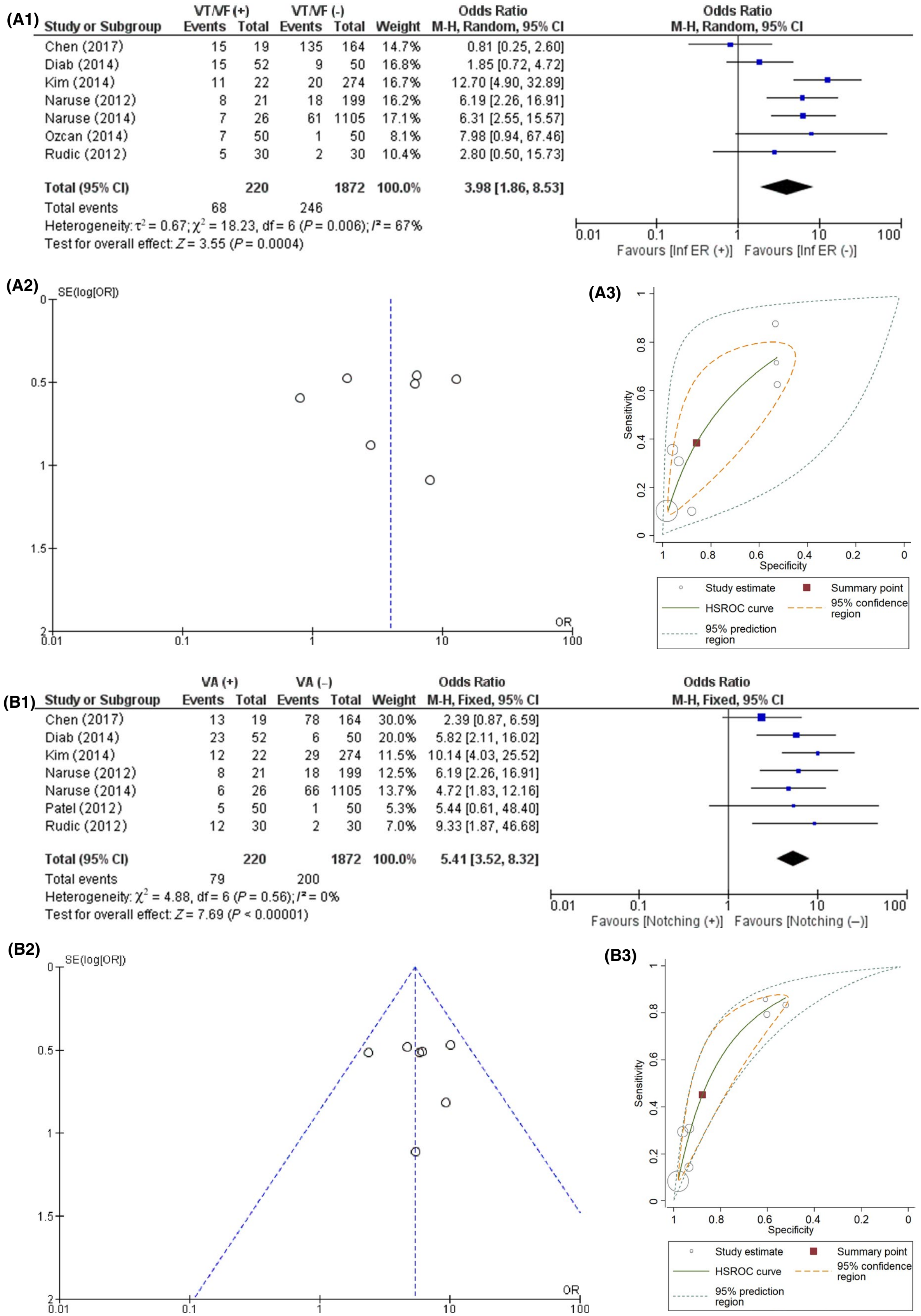

FIGURE 3 Characteristics of early repolarization that is associated with ventricular arrhythmias. Morphological characteristics of Early Repolarization associated with Ventricular Arrhythmias include location of ER, notching, J-point elevation, and horizontal ST-segment. (A), showed an association between inferior location of ER and VA. Notching of J-wave was associated with VA (B). (C), showed a pooled analysis of J-Point elevation and VA, showing a significant association. (D), showed a pooled analysis of horizontal ST-segment and VA. Description: ER, Early Repolarization; ST, ST-segment; VA, Ventricular Arrhythmia

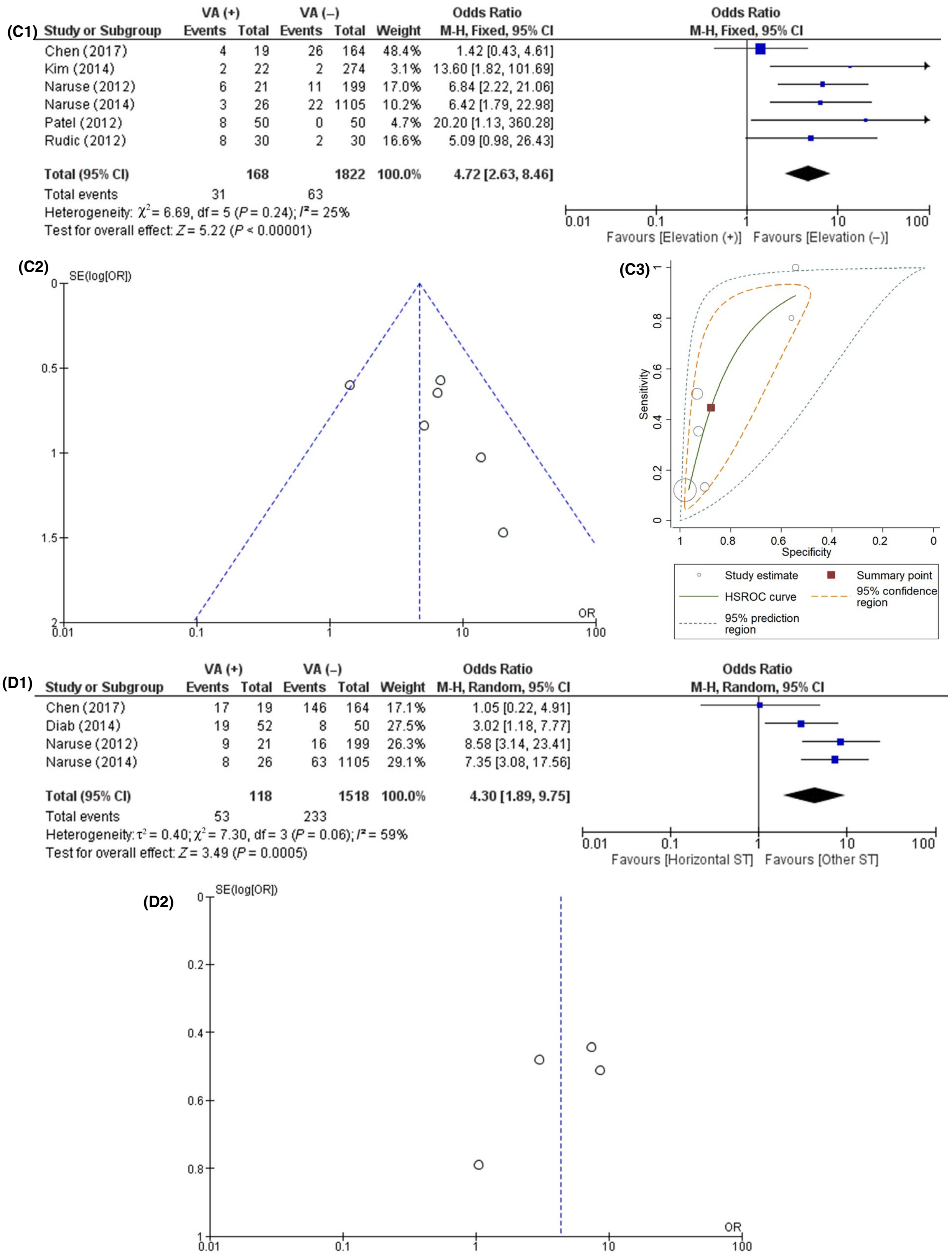

FIGURE 3 (Continued)

also includes sustained VT. Since the studies were mostly measuring the association between ER and VA as a whole, we did not know whether the increase VT or VF risk was more prominent in one than another. This may affect the pooled measure of our meta-analysis.

Early repolarization is also postulated to be a risk factor for VF in patients with coronary vasospasm. A study by Shinohara et al[21] reported that ER is an independent predictor of VF in patients with variant angina caused by reversible coronary vasospasm. Also reported by Oh et al,[22] that ER was associated with an increased risk of cardiac death, aborted sudden cardiac death, and fatal arrhythmia in patients with vasospastic angina. Oh et al also found that ER was observed in 21.4% of patients with vasospastic angina. According to a study in Japan, coronary artery vasospasm may mimic ER by presenting with inferolateral J wave.[23] Hence, it should be noted that ER may also be silent coronary vasospasm in disguise.

Limitation in this systematic review includes the different type of study design that is mostly retrospective. Selection bias also limits this systematic review because negative finding research is less likely to be published. The definition of ER also slightly differs from one study to another. The studies also have a different outcome measured that varies including VT and VF, VT/VF/sudden death, VT/VF/nsVT, and VF only that obscure the results. The studies sample also differ; some included STEMI only, anterior STEMI only, acute myocardial infarction in general, and STEMI undergoing PCI. These may differ in prognosis to one another although the controls were adjusted to the cases in the respective study. One of the major issues is the difference in ECG timing related to AMI, however, upon subgroup analysis, the results were still significant. Elevation of J point may be a concern during acute coronary ischemia, however, most of these studies assessed ER before AMI or after the resolution of ST-segment changes; one study did assess during acute ischemia, however, it only assesses ER in leads that are unaffected in the population (anterior only). Mortality and MACE also lacked data, only 2 studies reported the mortality. Hence, ER may or may not reflects increased mortality. We have performed a subgroup analysis on STEMI, however, similar analysis on non-ST segment elevation acute coronary syndrome (NSTE-ACS) is not possible; because there is no study that excluded STEMI and the present studies did not divide their outcome based on STEMI and NSTE-ACS.

5 | CONCLUSION

Early repolarization especially those with the inferior location, notching of J-wave morphology, an elevated J-point, and horizontal ST-segment had a higher likelihood of VA in AMI patients. ER in STEMI patients was associated with the VA. Lateral location ER, slurred J-wave, and upsloping ST-segment were not associated with an increase in VA. We suggest prospective cohort studies and inclusion of ER in acute coronary syndromes registry since ER is associated with three to fourfold risk of ventricular arrhythmias in a patient with AMI, hence, a significant prognostic indicator. We also suggest that all studies that evaluate ER and AMI to include mortality and MACE in addition to VA only.

CONFLICT OF INTEREST

Authors declare no conflict of interests for this article.

AUTHORS CONTRIBUTION

Raymond Pranata conceived and designed the study and drafted the manuscript. Emir Yonas and Rachel Vania acquired the data and drafted the manuscript. Raymond Pranata and Emir Yonas interpreted the data. Bambang Budi Siswanto, Budhi Setianto, and Sunu Budhi Raharjo performed extensive research and critically revised the manuscript. All authors contributed to the writing of the manuscript. Raymond Pranata analyzed the data statistically.

ORCID

Raymond Pranata https://orcid.org/0000-0003-3998-6551
Emir Yonas https://orcid.org/0000-0002-8604-405X
Rachel Vania https://orcid.org/0000-0002-4780-6592
Sunu Budhi Raharjo https://orcid.org/0000-0001-5749-8231
Bambang Budi Siswanto https://orcid.org/0000-0003-3998-1590

REFERENCES

1. Macfarlane PW, Antzelevitch C, Haissaguerre M, Huikuri HV, Potse M, Rosso R, et al. The early repolarization pattern. J Am Coll Cardiol. 2015;66(4):470–7. https://doi.org/10.1016/j.jacc.2015.05.033
2. Klatsky AL, Oehm R, Cooper RA, Udaltsova N, Armstrong MA. The early repolarization normal variant electrocardiogram: correlates and consequences. Am J Med. 2003;115(3):171–7. http://www.ncbi.nlm.nih.gov/pubmed/12935822. Accessed February 8, 2019.
3. Mehta M, Jain AC, Mehta A. Early repolarization. Clin Cardiol. 1999;22(2):59–65. http://www.ncbi.nlm.nih.gov/pubmed/10068841. Accessed February 8, 2019.
4. Sinner MF, Reinhard W, Müller M, Beckmann BM, Martens E, Perz S, et al. Association of early repolarization pattern on ECG with risk of cardiac and all-cause mortality: a population-based prospective cohort study (MONICA/KORA). PLoS Medicine. 2010;7(7):e1000314. https://doi.org/10.1371/journal.pmed.1000314
5. Kalla H, Yan G-X, Marinchak R. Ventricular fibrillation in a patient with prominent J (Osborn) waves and ST segment elevation in the inferior electrocardiographic leads. J Cardiovasc Electrophysiol. 2000;11(1):95–8. https://doi.org/10.1111/j.1540-8167.2000.tb00743.x
6. Haïssaguerre M, Derval N, Sacher F, Jesel L, Deisenhofer I, de Roy L, et al. Sudden cardiac arrest associated with early repolarization. N Engl J Med. 2008;358(19):2016–23. https://doi.org/10.1056/NEJMoa071968
7. Rosso R, Kogan E, Belhassen B, Rozovski U, Scheinman MM, Zeltser D, et al. J-point elevation in survivors of primary ventricular fibrillation and matched control subjects. J Am Coll Cardiol. 2008;52(15):1231–8. https://doi.org/10.1016/j.jacc.2008.07.010

8. Tikkanen JT, Anttonen O, Junttila MJ, Aro AL, Kerola T, Rissanen HA, et al. Long-term outcome associated with early repolarization on electrocardiography. N Engl J Med. 2009;361(26):2529–37. https://doi.org/10.1056/NEJMoa0907589
9. Patel RB, Ng J, Reddy V, Chokshi M, Parikh K, Subacius H, et al. Early repolarization associated with ventricular arrhythmias in patients with chronic coronary artery disease. Circ Arrhythmia Electrophysiol. 2010;3(5):489–95. https://doi.org/10.1161/CIRCEP.109.921130
10. Patel RB, Ilkhanoff L, Ng J, Chokshi M, Mouchli A, Chacko SJ, et al. Clinical characteristics and prevalence of early repolarization associated with ventricular arrhythmias following acute ST-elevation myocardial infarction. Am J Cardiol. 2012;110(5):615–20. https://doi.org/10.1016/j.amjcard.2012.04.042
11. Chen Q, Zheng M, Liu G, Shi X, Zhang R, Zhou X, et al. Early repolarization pattern predicts the increased risk of ventricular arrhythmias in patients with acute anterior ST-segment elevation myocardial infarction-a propensity analysis. Circ J. 2017;81(9):1346–53. https://doi.org/10.1253/circj.cj-16-1311
12. Ali Diab O, Abdel-Hafez Allam RM, Mohamed HG, Mohamed TR, Abel-Hafeez Khalid S. Early repolarization pattern is associated with increased risk of early ventricular arrhythmias during acute ST segment elevation myocardial infarction. Ann Noninvasive Electrocardiol. 2015;20(5):474–80. https://doi.org/10.1111/anec.12249
13. Naruse Y, Tada H, Harimura Y, Ishibashi M, Noguchi Y, Sato A, et al. Early repolarization increases the occurrence of sustained ventricular tachyarrhythmias and sudden death in the chronic phase of an acute myocardial infarction. Circ Arrhythmia Electrophysiol. 2014;7(4):626–32. https://doi.org/10.1161/CIRCEP.113.000939
14. Naruse Y, Tada H, Harimura Y, Hayashi M, Noguchi Y, Sato A, et al. Early repolarization is an independent predictor of occurrences of ventricular fibrillation in the very early phase of acute myocardial infarction. Circ Arrhythmia Electrophysiol. 2012;5(3):506–13. https://doi.org/10.1161/CIRCEP.111.966952
15. Özcan KS, Güngör B, Tatlisu MA, Osmonov D, Ekmekçi A, Çalık AN, et al. Presence of early repolarization on admission electrocardiography is associated with long-term mortality and MACE in patients with STEMI undergoing primary percutaneous intervention. J Cardiol. 2014;64(3):164–70. https://doi.org/10.1016/j.jjcc.2013.12.007
16. Park YM, Kang WC, Suh SY, Lee K, Han SH, Shin MS, et al. Early repolarization is associated with atrial and ventricular tachyarrhythmias in patients with acute ST elevation myocardial infarction undergoing primary percutaneous coronary intervention. Int J Cardiol. 2014;176(2):327–32. https://doi.org/10.1016/j.ijcard.2014.06.006
17. Kim SH, Kim DH, Park SD, Baek YS, Woo SI, Shin SH, et al. The relationship between J wave on the surface electrocardiography and ventricular fibrillation during acute myocardial infarction. J Korean Med Sci. 2014;29(5):685–90. https://doi.org/10.3346/jkms.2014.29.5.685
18. Rudic B, Veltmann C, Kuntz E, Behnes M, Elmas E, Konrad T, et al. Early repolarization pattern is associated with ventricular fibrillation in patients with acute myocardial infarction. Hear Rhythm. 2012;9(8):1295–300. https://doi.org/10.1016/j.hrthm.2012.03.006
19. Merchant FM, Noseworthy PA, Weiner RB, Singh SM, Ruskin JN, Reddy VY. Ability of terminal QRS notching to distinguish benign from malignant electrocardiographic forms of early repolarization. Am J Cardiol. 2009;104(10):1402–6. https://doi.org/10.1016/j.amjcard.2009.06.062
20. Hreybe H, Saba S. Location of acute myocardial infarction and associated arrhythmias and outcome. Clin Cardiol. 2009;32(5):274–7. https://doi.org/10.1002/clc.20357
21. Shinohara T, Kondo H, Fukui A, Akioka H, Teshima Y, Yufu K, et al. Early repolarization is involved in ventricular fibrillation in patients with variant angina. Pacing Clin Electrophysiol. 2018;41(7):734–40. https://doi.org/10.1111/pace.13355
22. Oh CM, Oh J, Shin DH, Hwang HJ, Kim BK, Pak HN, et al. Early repolarization pattern predicts cardiac death and fatal arrhythmia in patients with vasospastic angina. Int J Cardiol. 2013;167(4):1181–7. https://doi.org/10.1016/j.ijcard.2012.03.116
23. Kamakura T, Wada M, Ishibashi K, Inoue YY, Miyamoto K, Okamura H, et al. Significance of coronary artery spasm diagnosis in patients with early repolarization syndrome. J Am Heart Assoc. 2018;7(4):e007942. https://doi.org/10.1161/JAHA.117.007942

How to cite this article: Pranata R, Yonas E, Vania R, Raharjo SB, Siswanto BB, Setianto B. Electrocardiographic early repolarization is associated with future ventricular arrhythmia after acute myocardial infarction—Systematic Review and Meta-Analysis. *J Arrhythmia*. 2019;35:626–635. https://doi.org/10.1002/joa3.12196