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Incidence of left ventricular thrombus following STEMI in the modern era via multimodality imaging: A systematic review and meta-analysis

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ABSTRACT

Background: Left ventricular thrombus (LVT) is a significant complication in STEMI. Previous studies were conducted prior to modern timely percutaneous reperfusion networks. Current expert opinion suggests incidence in the current era has decreased. We conducted a systematic review and *meta*-analysis to better understand the incidence and diagnosis of LVT in patients with STEMI treated with timely percutaneous techniques as assessed by multimodality imaging.

Methods: Cochrane, EMBASE, LILACS, and MEDLINE were searched over the last 10 years only including studies using contemporary techniques. The primary outcome was detection of LVT in patients via echocardiogram with or without contrast or Cardiac MRI (cMRI) following STEMI (both anterior and any territory) treated with PCI. Data was pooled across studies and statistical analysis was conducted via random effects model.

Results: 31 studies were included. 18 studies included data on any territory STEMI, totaling 14,172 patients, and an incidence of 5.6% [95% CI 4.3–7.0]. 18 studies were included in analysis for anterior STEMI, totaling 7382 patients and incidence of 12.7% [95% CI 9.8–15.6]. Relative to cMRI as a gold standard, the sensitivity of non-contrast echocardiography to detect LVT was 58.2% [95% CI 46.6–69.2] with a specificity of 97.8% [95% CI 96.3–98.8].

Conclusions: Incidence of LVT in STEMI patients treated with contemporary timely percutaneous revascularization is in keeping with historical data and remains significant, suggesting this remains an ongoing issue for further investigation. Numerically, both cMRI and contrast echo detected more LVT compared to non-contrast echo in any-territory STEMI patients.

1. Introduction

Left Ventricular Thrombus (LVT) is a recognized complication following an ST-elevation myocardial infarction (STEMI), predominantly occurring within the first three months, and frequently involving the left anterior descending artery. Additionally, LVT is associated with an increased risk of embolic events, with an estimated 13 % likelihood following LVT [1]. Risk factors for LVT include anterior STEMI (aSTEMI), large infarct size, apical wall motion abnormalities, delayed reperfusion, and reduced left ventricular ejection fraction after primary percutaneous coronary intervention (pPCI) [2,3]. Recent *meta*-analyses have revealed varying incidences of LVT. One such analysis reports an incidence of roughly 4 % in all-territory STEMI patients and 10 % in aSTEMI patients treated with pPCI [4]. A 2018 *meta*-analysis using cardiac magnetic resonance imaging (cMRI) reported slightly higher values: 6.3 % in all-territory STEMI and 12.2 % in aSTEMI [5]. cMRI remains the gold standard for detecting the presence, size and location of LVT [6]. However, echocardiography, which may be performed with or without contrast, is often preferred due to its lower cost and greater accessibility [7,8]. Despite numerous studies on the risk factors and incidence of LVT in STEMI patients, results vary across studies, warranting further investigation. With the advent of timely pPCI, the prevalence of LVT has declined [5,9], indicating the need for an updated *meta*-analysis to characterize LVT incidence in the context of modern pPCI practices across different cardiac regions and imaging modalities.

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2. Methods

2.1. Search strategy, study selection and data extraction

Electronic databases, including EMBASE, MEDLINE, LILACS and the Cochrane Library were systematically searched over the last 10 years, according to the principles of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guideline [10]. The search strategy included the following terms: "STEMI", "myocardial infarction", "LVT", "LV Thrombus", "echocardiography", "cardiac magnetic resonance" and "CMR". The literature search was conducted in March 2022 and a detailed search strategy is presented in eTable 1, eTable 2 and eTable 3 of the Supplement.

Two independent reviewers (A.E.S and P.D) performed literature screening and data extraction. Any inconsistencies were reviewed and resolved by a third reviewer (B.A). To be considered for inclusion, studies needed to meet the following criteria:

1. Population of adult (≥18 year old) human patients diagnosed with STEMI.
2. pPCI used as the lone revascularization technique.
3. LV thrombi diagnosed using echocardiography or cMRI within 90 days of STEMI.
4. Primary study design published in English.
5. Study published since 2012.

Pertinent data from the included studies were recorded in a predefined electronic data extraction form. This form covered study characteristics, patient demographics, and outcomes. To ensure accuracy, the data presented in the *meta*-analysis was compared with the information in the data extraction form. Any inconsistencies were resolved through a consensus among all authors.

Studies where patients received G2b3a inhibitors following STEMI were excluded. Studies in which patients received full dose anticoagulation following STEMI were also excluded. Studies of patients not treated solely with pPCI (i.e., patients who received thrombolysis) were excluded. Conference abstracts, editorials, review articles and non-primary studies were excluded. All authors verified the pertinence and completeness of the articles included in this review.

2.2. Risk of bias assessment

The risk of study bias was assessed for each included study according to the criteria in the Cochrane Handbook for systematic reviews (version 5.1.0) [11]. The bias assessment addressed 5 domains, including selection bias, performance bias, detection bias, attrition bias and reporting bias (see eTable 4 of the Supplement). Each category was rated as "low risk", "high risk" or "unclear". Risk of bias was assessed relative to the outcome measure of LVT, and publication bias was assessed through inspection of funnel plots (see eFig. 1 and eFig. 2 of the Supplement).

2.3. Data analysis

The primary outcome measure was the detection of LVT in patients using echocardiography (with or without contrast) and/or cMRI, following STEMI treated with pPCI. The incidence of LVT and 95 % confidence intervals (CIs) were calculated for each included study. Data were pooled using a random-effects *meta*-analysis, following the classical method proposed by Borenstein et al. (2010) [12]. This method employs untransformed proportions and their corresponding standard errors in an inverse variance framework. Heterogeneity among studies was assessed using the I^2 statistic, with values considered low, moderate, or considerable for $I^2 < 25$ %, 25–50 % and > 50 %, respectively. All p values < 0.05 were considered significant and all statistical analysis was performed using R software version 4.3.2.

3. Results

3.1. Inclusion studies

The literature search yielded 4382 abstracts, of which 478 were removed due to duplication. Two authors independently reviewed 3904 abstracts, resulting in 120 articles (3.1 %) being selected for full-text review. Ultimately, 31 studies (0.79 %) were included in this systematic review, comprising fifteen retrospective cohort studies and sixteen prospective cohort studies. Eighteen studies included data on STEMI occurring in any territory, accounting for a total of 14,172 individual patients, while eighteen studies provided analysis on aSTEMI, encompassing 7382 individual patients. In the studies assessing STEMI in any territory, seven used echocardiography without contrast (n = 6751 patients), four with contrast (n = 3214 patients), seven utilized cMRI (n = 2076 patients), and two combined echocardiography with cMRI (n = 2535 patients). Among the studies examining aSTEMI, eleven employed echocardiography without contrast (n = 5278 patients), three with contrast (n = 1272 patients), four used cMRI (n = 739 patients), and one combined echocardiography with cMRI (n = 171 patients). A PRISMA flow diagram illustrating the literature search and study selection process is presented in Fig. 1.

3.2. Baseline study characteristics

Among the included studies, baseline demographic characteristics, including age, percentage of diabetes mellitus, smoking status, hyperlipidemia, hypertension and gender distribution, were well-balanced. Observational studies were included from a variety of different countries internationally. The mean patient ages ranged from 55 to 67 years. Male sex predominated in all studies, ranging from 63 to 89 % of participants. Study sample size ranged from 36 to 2608 with a median [IQR] of 392 [210–1045] patients. A summary of the included articles is outlined in Table 1 and Table 2.

3.3. All-territory STEMI

The studies addressing LVT outcomes in all-territory STEMI (n = 18) had a median [IQR] of 382.5 [210–1261] patients. Subgroup analysis, using a random-effects model, revealed an LVT incidence of 4.3 % [95 % CI 2.6—–6.0] in studies employing echocardiography without contrast, 4.6 % [95 % CI 1.6—–7.5] with contrast, 7.4 % [95 % CI 5.0—–9.8] using cMRI, and 7.9 % [95 % CI 0.9—–14.9] using both echocardiography and cMRI. Overall, the pooled LVT incidence was 5.6 % [95 % CI 4.3—–7.0] (Fig. 2). Statistical heterogeneity among the individual studies was significant, with an I^2 value of 90 %. According to the random effects model, there was no statistically significant difference in the incidence of LVT between the different subgroups of imaging modality.

Among the studies that investigated STEMI across all territories, 16 reported data on the location of individual STEMI cases. All 16 studies observed a majority of LVT occurrences in anterior STEMI cases, with reported data ranging from 81 % to 100 % and an average of approximately 89 %. In non-anterior STEMIs where LVT was present, right coronary artery infarcts were more prevalent, at about 9 %, compared to left circumflex artery infarcts, which accounted for 2 % to 3 %. Conversely, in the subgroup where LVT was not observed, there was an almost equal distribution of anterior and non-anterior STEMI cases (eTable 5 of the supplement).

3.4. Anterior STEMI

The studies examining LVT outcomes following anterior-STEMI (n = 18) had a median [IQR] of 359 [205–454] patients. Pooled subgroup analysis using a random-effects model indicated an LVT incidence of 13.0 % [95 % CI 8.9—–17.1] for echocardiography without contrast,

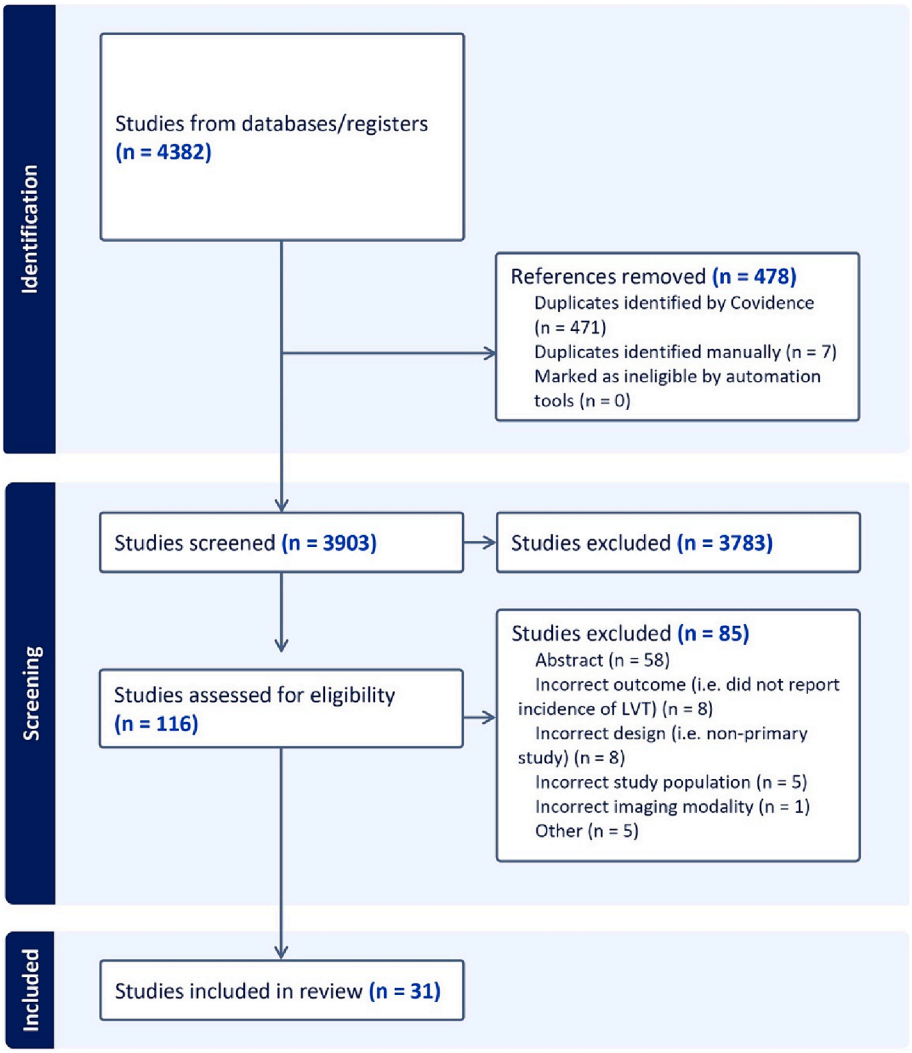

Fig. 1. PRISMA diagram of the search strategy.

7.7 % [95 % CI 6.2—9.1] with contrast, 14.7 % [95 % CI 7.4—22.0] for cMRI, and 19.9 % [95 % CI 14.2—26.7] for the combination of echocardiography and cMRI. Overall, the combined LVT incidence was 12.7 % [95 % CI 9.8—15.6] for the pooling of all anterior-STEMI studies (Fig. 3). The statistical heterogeneity among the studies was significant, with an I^2 value of 91 %. According to the random effects model, there was no statistically significant difference in the incidence of LVT between the different types of imaging modalities.

3.5. Predisposing factors for LVT formation

Previously cited risk factors for LVT formation include large infarct size, severe LV systolic dysfunction (LVEF ≤ 40 %), LV aneurysm, severe apical asynergy (i.e., akinesis or dyskinesis), delayed reperfusion and anterior MI. Regarding the occurrence of LV aneurysm, 7 out of the 31 included studies reported outcome data stratified by the presence (LV +) or absence (LV-) of left ventricular thrombus. The combined odds ratio of LV aneurysm, calculated using a random-effects model, is presented in Fig. 4. Our results are in alignment with the existing literature, which indicates a higher proportion of LV apical aneurysm on cardiac imaging when LVT is present following STEMI (OR = 6.91, 95 % CI = 3.16–15.10, P < 0.01).

In addition, reduced LVEF (LVEF ≤ 40 %) has been identified as a predisposing factor for LVT formation. Of the 31 studies included in our review, 26 provided LVEF data stratified by the presence or absence of LVT. Consistently, these studies demonstrated a higher average LVEF in the LV- group compared to the LV + group, as depicted in Fig. 5.

Regarding infarct size, 6 out of 31 studies reported data stratified by the presence of LVT. Four of these studies presented infarct size as a percentage of total LV size, while two reported it in grams. Across all six of these studies, the mean infarct size was larger in the LV + group compared to the LV- group (Supplement eTable6).

3.6. Sensitivity and specificity of non-contrast echocardiography against cMRI

The diagnostic performance of non-contrast echocardiography, relative to cMRI, was analyzed to determine its sensitivity and specificity, using cMRI as the gold standard. Three studies [13–15] presented data on LVT detection by both non-contrast echocardiography and cMRI in an all-territory STEMI population. Among the patients with both cMRI and echocardiography data (n = 712), the sensitivity of echocardiography was 58.2 % [95 %CI 46.6–69.2] with a specificity of 97.8 % [95 % CI 96.3–98.8], using cMRI as the reference standard.

3.7. Bias assessment

Among the studies used in our analysis (n = 31), one was deemed high risk for selection bias [16]. One study was deemed high risk for performance bias [17]. All studies were evaluated as low risk for

Table 1
Baseline patient characteristics of included studies.

Study	Age (LV+/LV-)	% Male (LV+/LV-)	% Smoking (LV+/LV-)	% Dyslipidemia (LV+/LV-)	% Hypertension (LV+/LV-)	% Diabetes (LV+/LV-)	LVEF % (LV+/LV-)	% Patients treated with pPCI
Acar 2014 [35]	62.72 ± 13.50 61.25 ± 12.93	86.3/86.3	54.5/52.1	NR	50/46.5	22.7/17.3	31.70 ± 7.14 44.70 ± 10.75	100
Ali-Barman 2020 [36]	59.24 ± 11.70 55.74 ± 14.18	85/77	64/52	50/48	38/45	23/30	31.40 ± 4.10 37.75 ± 3.17	100
Altintas 2019 [18]	64(58–70) 59(50–69)	61.6/72.2	38.4/41.9	24.7/25.7	28.8/25.9	28.8/17.1	31(30–35) 36(33–39)	100
Bayam 2021 [37]	61.1 ± 14.8 56.1 ± 12.0	71.9/84.1	78.1/68.2	68.8/67.6	62.5/58.4	37.5/22.5	33.1 ± 7.2 44.2 ± 10.5	100
Choi 2018 [38]	66 ± 11 64 ± 12	85/71	60/49	38/40	47/49	21/27	35 ± 11 48 ± 11	100
Cirakoglu 2020 [39]	60(53–63) 60(55-63)	82.5/76.2	38.9/35	75.4/76.7	45.2/37.3	36.5/28.5	34(30–36) 39(34–44)	100
Garber 2016 [40]	60(51–66) 61(51–71)	76/65	41/39	43/44	51/57	22/20	34(27–45) 49(40–59)	NR
Gokdeniz 2014 [41]	64.4 ± 13.5 59.2 ± 14.8	78.1/82.8	43.8/53.9	NR	71.9/49.2	25/21.9	38.5 ± 4.2 45.2 ± 6.9	91
Khoury 2017 [42]	64 ± 11 61 ± 13	80/81	42/51	45/47	32/44	19/23	38 ± 6.9 47 ± 8.2	100
Moss 2019 [17]	58.7 ± 12.8 62.0 ± 12.5	77.5/71.5	65/58.5	25.0/40.5	25.0/32.7	12.5/12.9	NR	100
Olsen 2020 [43]	60 ± 13 62 ± 11	81/75	39/53	26/16	13/8	13/8	39 ± 10 46 ± 9	100
Ratnayake 2020 [44]	55(32–87) NR	70/NR	NR	60/NR	NR	17/NR	38(15–53) NR	100
Shacham 2013 [9]	62 ± 12 61 ± 13	78/78	44/52	44/57	39/61	89/81	39 ± 4 42 ± 6	100
Zhang 2019 [45]	60(50–70) 60(51–69)	78.3/74.4	46.2/52.6	26.4/21.2	40.6/48.1	26.4/21.2	43 (39–48) 48(41–53)	100
Zhang 2020 [46]	59.63 ± 11.75 61.01 ± 11.51	78.3/79.7	56.5/55.8	NR	32.6/39.6	19.6/20.7	39.84 ± 10.05 41.78 ± 6.72	100
Duus 2021 [47]	NR	NR	NR	NR	NR	NR	39 ± 10 47 ± 9	100
Gianstefani 2014 [48]	62 ± 14 61 ± 13	83/74	44/42	43/49	43/49	7/16	35 ± 8 47 ± 10	100
Mao 2018 [49]	62 ± 15 61 ± 13	79/71	43/55	NR	57/62	21/22	36 ± 12 51 ± 12	100
Meimoun 2021 [50]	59 ± 12	68	37	49	41	18	NR	85
Tan 2022 [51]	55.17 ± 12.43 59.78 ± 12.78	79.3/80.6	44.8/62.1	48.3/37.7	51.7/47.7	37.9/24.7	NR	100
Wada 2014 [52]	NR	NR	NR	NR	NR	NR	NR	NR
Biere 2016 [53]	57.3 ± 9.5 58.5 ± 11.3	86/82	36/44	22/51	18/33	13/4	39.6 ± 8.0 48.0 ± 9.7	100
Cambronero-Cortinas 2017 [19]	58 ± 13 58 ± 12	85/82	59/60	44/43	37/47	22/18	40 ± 11 53 ± 13	100
Eitel 2015 [54]	61(48–68) 62(51 – 71)	73/76	38/47	19/37	50/67	28/19	36 (31–47) 51(44–58)	99
Lanzillo 2013 [16]	57 ± 12 59 ± 10	86/90	57/72	42/41	0/48	14/24	39.2 ± 6 51.5 ± 10	100
Surder 2015 [55]	56.8(10.2)	91/85	73/58	55/41	55/41	10.8/27	35.2 ± 6.3 37.8 ± 9.7	97
Jones 2021 [56]	59.61 ± 14.1 64.88 ± 15.1	85.1/76.3	27.7/30.3	37.6/36.0	44.6/46.4	16.8/18.7	34.5 ± 9.6 46.1 ± 14.0	95
Khaled 2020 [15]	55 ± 10 56 ± 11	92/82	NR	17/14	47/47	53/54	31 ± 2 40 ± 1	100
Delewi 2012 [13]	57 ± 8 56 ± 10	82/85	35/54	6/21	24/28	0/7	37 ± 10 43 ± 9	100
Meurin 2015 [6]	57.4 ± 12.7 59.7 ± 11.9	76.1/70.3	46.2/41.9	16.9/44.6	26.9/35.1	11.5/23.0	34.1 ± 6.6 39.0 ± 9.2	88
Phan 2019 [14]	NR	85/84	54/58	50/45	58/4	19/20	34.9 ± 7.5 47.4 ± 8.9	80

Values are reported as median, median (interquartile range) or mean ± standard deviation LV+ = left ventricular thrombus present, LV- = left ventricular thrombus absent, NR = not recorded, LVEF = left ventricular ejection fraction, pPCI = primary percutaneous coronary intervention

Table 2
Characteristics of included studies.

Study	STEMI Territory	Country	Type of Study	Imaging Modality	All-STEMI (n)	aSTEMI (n)
Acar 2014	aSTEMI	Turkey	Retrospective	Echo w/o contrast	–	205
Ali-Barman 2020	aSTEMI	Turkey	Retrospective	Echo w/o contrast	–	211
Altintas 2019	aSTEMI	Turkey	Retrospective	Echo w/o contrast	–	641
Bayam 2021	aSTEMI	Turkey	Retrospective	Echo w/o contrast	–	378
Choi 2018	aSTEMI	South Korea	Retrospective	Echo w/o contrast	–	1045
Cirakoglu 2020	aSTEMI	Turkey	Prospective	Echo w/o contrast	–	955
Garber 2016	all-STEMI	USA	Retrospective	Echo w/o contrast	1734	NR
Gokdeniz 2014	aSTEMI	Turkey	Prospective	Echo w/o contrast	–	160
Khoury 2017	all-STEMI	Israel	Retrospective	Echo w/o contrast	2071	NR
Moss 2019	all-STEMI	United Kingdom	Prospective	Echo w/o contrast	2608	720
Olsen 2020	all-STEMI	Denmark	Prospective	Echo w/o contrast	373	177
Ratnayake 2020	all-STEMI	New Zealand	Retrospective	Echo w/o contrast	997	NR
Shacham 2013	aSTEMI	Israel	Retrospective	Echo w/o contrast	–	429
Zhang 2019	aSTEMI	China	Retrospective	Echo w/o contrast	–	1488
Zhang 2020	aSTEMI	China	Prospective	Echo w/o contrast	–	217
Duus 2021	all-STEMI	Denmark	Prospective	Echo + contrast	364	175
Gianstefani 2014	all-STEMI; aSTEMI	United Kingdom	Retrospective	Echo + contrast	1059	454
Mao 2018	all-STEMI	USA	Retrospective	Echo + contrast	1698	660
Meimoun 2021	all-STEMI	France	Prospective	Echo + contrast	93	NR
Tan 2022	aSTEMI	Australia	Retrospective	Echo + contrast	-	425
Wada 2014	aSTEMI	Japan	Prospective	Echo + contrast	–	392
Biere 2016	all-STEMI	France	Prospective	cMRI	638	183
Cambronero-Cortinas 2017	aSTEMI; all-STEMI	Spain	Prospective	cMRI	392	207
Eitel 2015	all-STEMI	Germany	Prospective	cMRI	738	325
Lanzillo 2013	all-STEMI	Italy	Retrospective	cMRI	36	19
Surder 2015	all-STEMI	Switzerland	Prospective	cMRI	177	164
Jones 2021	all-STEMI	United Kingdom	Prospective	Echo + cMRI	2328	905
Khaled 2020	aSTEMI; all-STEMI	Saudi Arabia	Retrospective	Echo + cMRI	308	171
Delewi 2012	all-STEMI	Netherlands	Prospective	Echo w/o contrast; cMRI	200	123
Meurin 2015	aSTEMI	France	Prospective	Echo w/o contrast; cMRI	-	100
Phan 2019	aSTEMI; all-STEMI	Australia	Prospective	Echo w/o contrast; cMRI	210	115

Echo = Echocardiogram; cMRI = Cardiac magnetic resonance imaging; w/o = without; aSTEMI = anterior-STEMI; all-STEMI = all-territory STEMI; NR = not recorded.

detection bias. Regarding attrition bias, two studies were classified as unclear [18,19], with the remainder assessed as low risk. Reporting bias was rated low across all studies, except for one [16].

In addition, the examination of funnel plots to assess publication bias revealed some asymmetry, particularly in smaller studies which tended to skew to the right side of the plots for both aSTEMI and all-territory STEMI groups. This distribution indicated an inverse relationship between study size and the reported incidence of LVT in these groups. Meta-regression plots illustrating the fitted model for this relationship can be found in eFig. 3 and eFig. 4 of the Supplement.

Furthermore, the article by Lanzillo et al. [16] emerged as an outlier in analysis of the all-STEMI population, showing the smallest sample size and the highest rate of LVT among all the studies. However, sensitivity analysis indicated that its inclusion in the random effects model did not significantly alter the overall findings. Excluding this study from our analysis for all-territory STEMI resulted in a pooled LVT incidence of 5.5 % [95 % CI 4.2—6.8], with the cMRI subgroup demonstrating an LVT incidence of 6.9 % [95 % CI 4.7—9.2].

4. Discussion

In this *meta*-analysis, we delve into the intricacies of LVT following STEMI, comparing the incidence across different infarct regions and cardiac imaging modalities. Although the modern rate of LVT is recognized to be lower than that of the pre-PCI era [20], discrepancies in reported values persist, underscoring the need for a clearer understanding of LVT's incidence post-STEMI. Our analysis reveals a 5.6 % rate of LVT across all-territory STEMI, escalating to 12.7 % in anterior STEMI. The higher incidence of LVT in anterior STEMI can be interpreted using Virchow's triad, emphasizing the role of hemostasis and endothelial injury in thrombus formation [21]. The left anterior descending artery, frequently the culprit artery in anterior STEMI, supplies a large myocardial area within the anterior and anteroapical region, leading to stasis and increasing the probability of LVT. Another predisposing factor for LVT involves apical akinesia or dyskinesia, commonly seen in anterior STEMI and detected by echocardiographic studies [22,23].

Previous *meta*-analyses on the detection of LVT after STEMI in the pPCI era include publications by Robinson et al. [24], Bulluck et al. [5] and Wang et al. [4]. Robinson et al. analyzed 19 observational studies from 1990 to 2015, focusing exclusively on echocardiography (2 with contrast, 17 without), and reported a 2.7 % rate of LVT in all-territory STEMI and 9.1 % in aSTEMI. Bulluck et al., analyzed data solely on cMRI up to 2018 from 10 studies, found a 6.3 % rate of LVT in all-territory STEMI and 12.2 % in aSTEMI. Wang et al. reviewed 18 studies conducted between 2001 and 2022, focusing on echocardiography with or without contrast. They reported an incidence of LVT of 4.0 % in all-STEMI cases and 10.0 % in aSTEMI. Our *meta*-analysis, encompassing 31 studies and focusing exclusively on the post-pPCI era, expands on these findings with a larger sample size (14172 all-STEMI patients, 7382 aSTEMI patients), examining multiple imaging modalities to provide a comprehensive overview of LVT incidence.

In our review, we assessed the sensitivity and specificity of non-contrast echocardiography compared to cMRI in all-territory STEMI patients. Our results are in line with prior publications reporting echocardiographic specificities of 95–98 % [5,25]. However, the sensitivity of echocardiography in detecting LVT, especially in aSTEMI versus all-STEMI, is not as well characterized. Our analysis demonstrated a sensitivity of 58.2 % [95 %CI 46.6–69.2] which was higher than previous estimates which ranged from 25 to 45 % [5,25]. Although based on a limited sample size, these findings are consistent with evidence suggesting that thrombi not visualized by echocardiography are typically small and mural [6,26,27]. Larger infarcts, more common in aSTEMI, may be less likely to be missed by echocardiography [15], indicating a higher sensitivity of echocardiography for LVT detection in aSTEMI compared to all-territory STEMI. Weinsaft et al. also noted increased sensitivity to 60 % in an all-territory STEMI population clinically suspected of having LVT [26]. Regarding the extent of myocardial

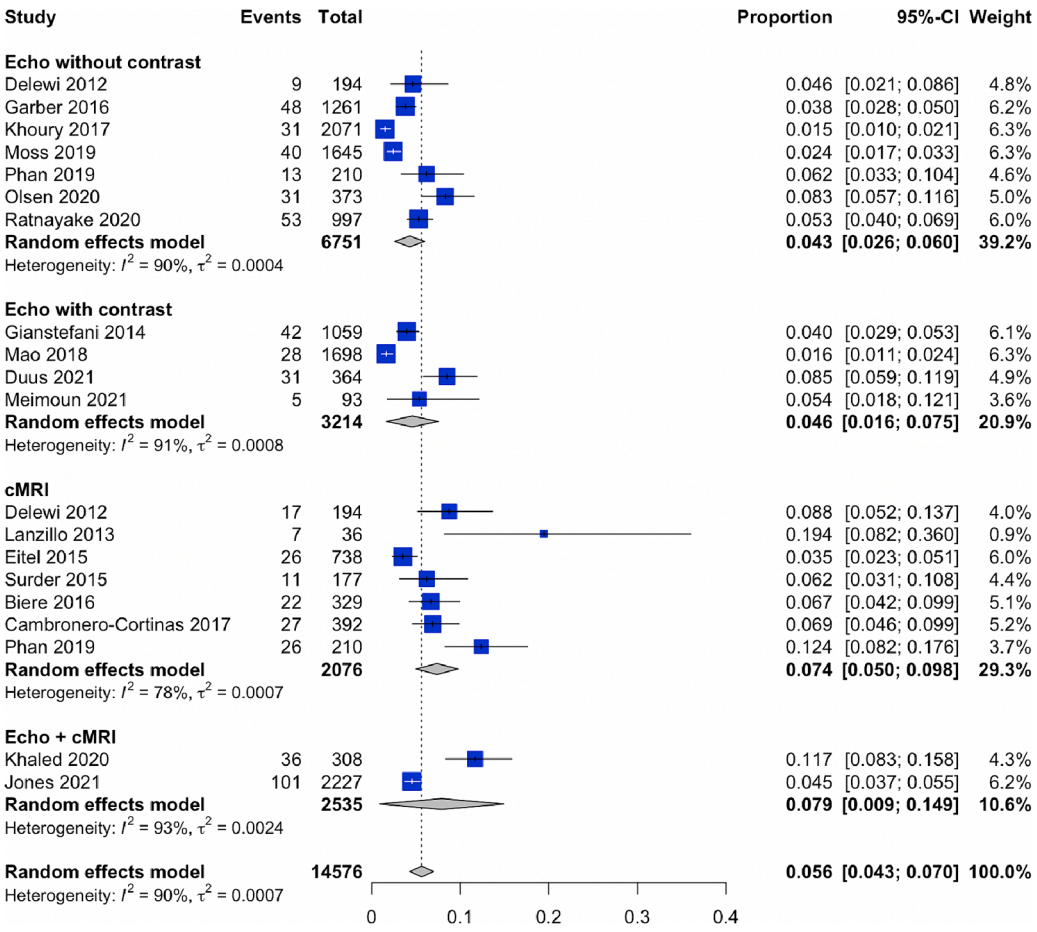

Fig. 2. Forest plot of random-effects model describing incidence of LVT in each study for all-territory STEMI, with subgroup analysis by imaging modality.

dysfunction in the presence of LVT, our preliminary findings indicate a trend towards elevated Wall Motion Score Index (WMSI) with LVT, as evidenced by a small sample from three studies detailed in eTable7 of the supplement. Due to the limited sample size, definitive conclusions cannot be drawn, highlighting the need for further research in this area.

With regards to differences in imaging modalities, we observed that cMRI, as the gold standard, typically shows higher LVT incidence than echocardiography with/without contrast (7.4 % vs 4.6 %/4.3 %). The highest incidence of 7.9 % was noted when both modalities were combined [4]. A similar trend was seen in aSTEMI, where echocardiography without contrast showed a 13.0 % incidence, cMRI 14.7 %, and a combined approach 19.9 %. While echocardiography relies on morphological identification of LVT, cMRI with gadolinium contrast detects LVT through both morphology and avascular tissue characteristics [27]. Although cMRI offers increased detection capabilities, its suitability for universal screening after STEMI is limited by high costs, low accessibility, and the specialized nature of its equipment. On the contrary, echocardiography is cost-effective, widely accessible, and can be performed at the bedside, which is specifically relevant in critically ill patients.

A recent study by DiOdoardo et al. revealed that among 104 European cardiac centers surveyed, only 23 % use a standardized protocol for LVT diagnosis and therapy. Echocardiograms are the primary imaging tool, with 75 % of centers performing them within the first 24 h and 22 % between 1 and 3 days. If initially no thrombus is detected, 88 % continue to monitor for LVT, with 38 % doing so routinely and 51 % only when risk factors are present. Notably, over a third of the centers in the study did not regularly assess LVT risk. Furthermore, only two-thirds of the centers considered using echocardiographic contrast agents, and less than half employed cMRI, typically when echocardiography results were inconclusive [28]. Our study aims to bridge these gaps identified by DiOdoardo et al., proposing the use of non-contrast echocardiography to identify post-myocardial infarction patients at high risk of thrombosis, allowing for targeted application of cMRI, particularly in aSTEMI patients. However, there is limited data on whether high-sensitivity detection improves patient outcomes or LVT resolution. The utility of a standardized protocol for LVT diagnosis and therapy in improving patient outcomes remains an area for further research.

This *meta*-analysis has several limitations that merit discussion. First, the random effects model involves substantial statistical heterogeneity, as reflected by I^2 values of 90 % for all-territory STEMI and 91 % for aSTEMI. Meta-regression suggests that this heterogeneity is partially related to disproportionately high rates of LVT formation reported in smaller studies. There is also variability in the proportion of aSTEMI patients across the studies, compounded by some studies (n = 6) applying a reduced left ventricular ejection fraction threshold (≤40 %). Variations in the timing of follow-up imaging (≤90 days), with the optimal period for LVT detection post-STEMI suggested to be around two weeks [5,6,29], may have influenced results. Subgroup and sensitivity analysis failed to identify the source of statistical heterogeneity. Another notable limitation was the unexpectedly lower rate of LVT in aSTEMI cases identified via echocardiography with contrast (7.7 %), compared to echocardiography without contrast (13.0 %). This disparity, likely due to the small number of studies in the contrast-echo subgroup (n = 3 studies) versus the non-contrast echo subgroup (n = 11 studies), warrants further investigation to clarify the effectiveness of echocardiography with and without contrast in anterior STEMI cases. This is particularly pertinent given that the ACC/AHA 2022 position statement on LVT advocates the use of echocardiographic contrast to enhance sensitivity [30]. Notably, this recommendation aligns with

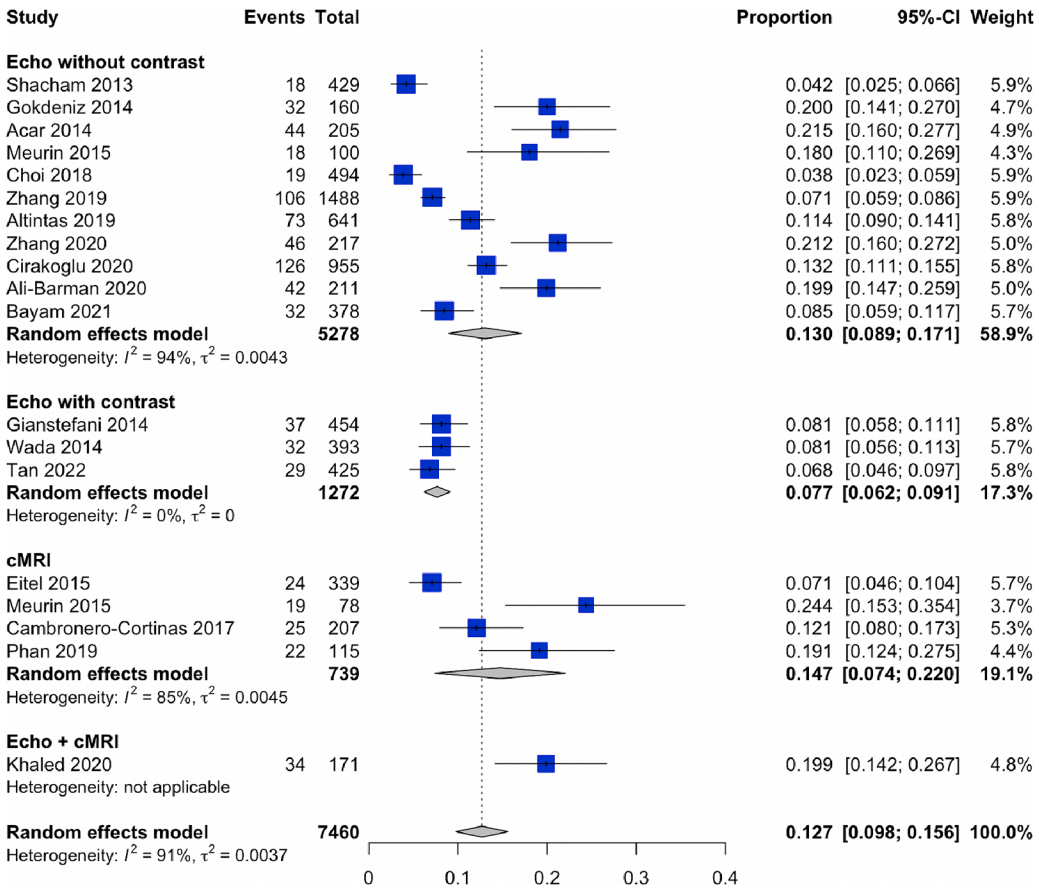

Fig. 3. Forest plot of random-effects model describing incidence of LVT in each study for anterior STEMI, with subgroup analysis by imaging modality.

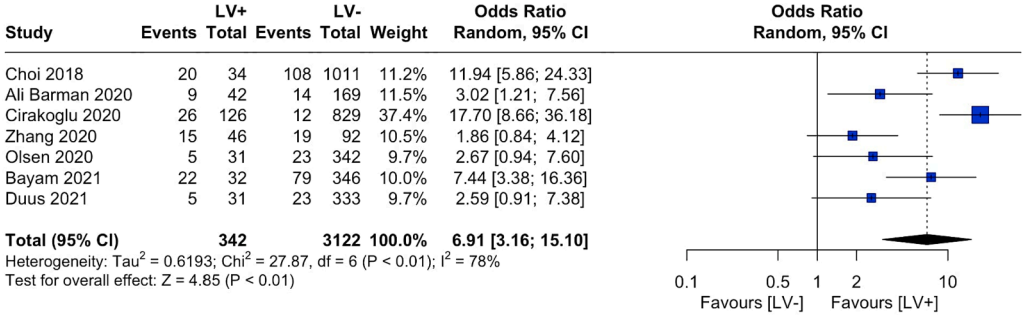

Fig. 4. Forest plot of random-effects *meta*-analysis describing odds ratio of LV aneurysm in subgroup of patients with left ventricular thrombus (LV +) versus those without (LV-).

practices already established across major centers, predating the statement. It is also important to mention that several factors influence the incidence of LVT, which were not addressed in this study. These factors include clinical, procedural, *peri*-procedural, genetic, and imaging variables, of which only some were addressed in the study. Therefore, accurately defining the true incidence of LVT is challenging due to these factors, which are difficult to account for.

One final source of uncertainty is the potential for publication bias, as indicated by asymmetry in our funnel plots. Our numerical analysis suggests that smaller sized studies were more likely to report a higher incidence of LVT, possibly due to selective reporting of case clusters in retrospective studies. Alternatively, the observed funnel plot asymmetry might reflect a volume-outcome relationship, with larger, high-volume centers reporting lower LVT incidence. This could be due to quicker and more effective pPCI provided by larger, more experienced institutions [31,32]. Similar observations were made by Robinson et al. in their analysis of aSTEMI patients and by Wang et al., who also noted funnel plot asymmetry for this clinical question [4,24].

5. Conclusions

In summary, this article significantly contributes to the evolving body of LVT data in the context of STEMI, representing the largest *meta*-analysis to date in the pPCI era on this topic. Incidence of LVT in STEMI patients treated with contemporary timely percutaneous revascularization is in keeping with historical data and remains significant, suggesting this remains an ongoing issue for further investigation. Numerically, both cMRI and contrast echocardiography detected more LVT compared to non-contrast echocardiography in any-territory STEMI patients. The study underscores the value of screening for LVT in aSTEMI patients but

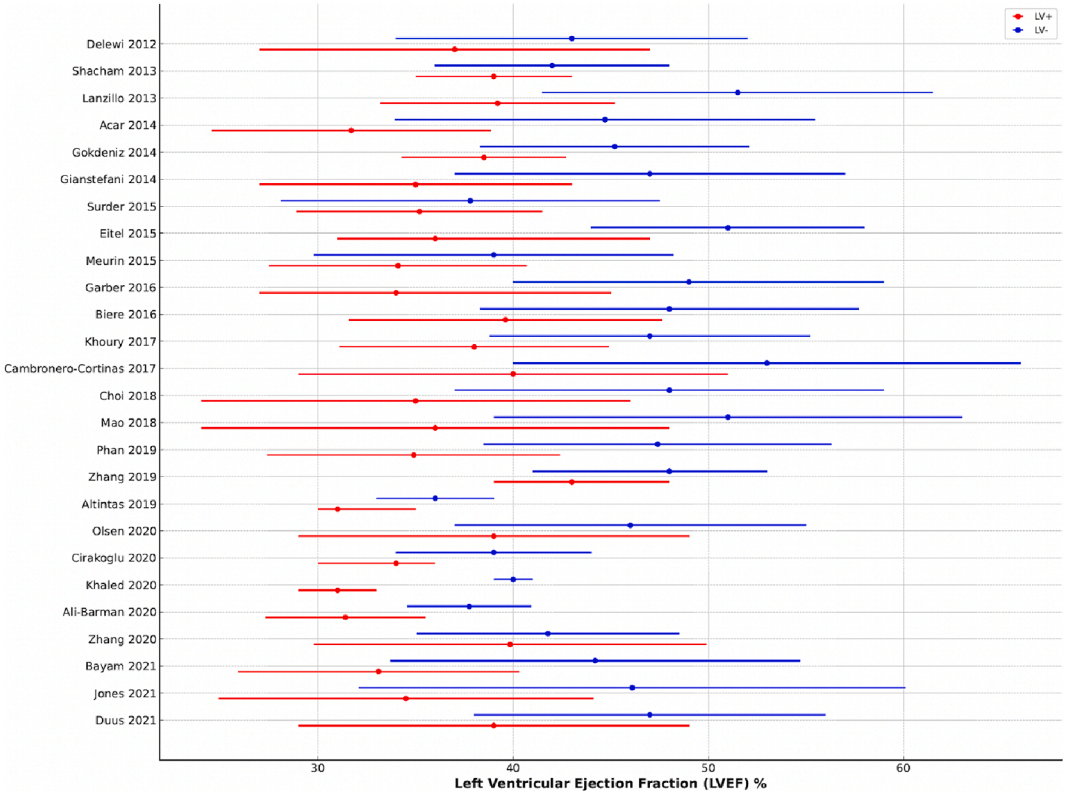

Fig. 5. LVEF data for LV+ (red) and LV- (blue) subgroups, sorted by study. Data reported as mean ± SD or median (interquartile range).

notes that data on whether high-sensitivity detection improves outcomes or LVT resolution remains limited [33,34].

CRediT authorship contribution statement

Ethan Sacoransky: Software, Validation, Visualization, Writing – original draft, Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing. **Danny Yu Jia Ke:** Formal analysis, Methodology, Resources, Validation, Writing – original draft, Writing – review & editing. **Prasham Dave:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Conceptualization, Supervision, Writing – original draft, Writing – review & editing. **Bryce Alexander:** Investigation, Methodology, Resources, Supervision, Validation, Writing – review & editing, Conceptualization, Data curation, Formal analysis. **Adham El Sherbini:** Data curation, Formal analysis, Investigation, Methodology, Resources, Validation. **Joseph Abunassar:** Project administration, Resources, Supervision, Validation, Conceptualization, Methodology. **Wael Abuzeid:** Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Conceptualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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