Influence of Previous Coronary Artery Bypass Grafting on Clinical Outcomes After Percutaneous Coronary Intervention: A Meta-Analysis of 250 684 Patients

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ABSTRACT

BACKGROUND: Percutaneous coronary intervention (PCI), also known as coronary angioplasty, is the preferred strategy for treating obstructive coronary artery disease. Existing literature suggests the worsening of clinical outcomes in patients with previous coronary artery bypass grafting (CABG) history. In light of this, a comprehensive systematic review and meta-analysis was performed.

METHODS: Databases including PubMed, Cochrane Library, and ScienceDirect were utilized for the inclusive systematic search dating from inception to September 01, 2023. The risk of bias assessment was performed using the Newcastle-Ottawa scale for cohort studies, and the Cochrane Risk of Bias Tool for randomized controlled trials.

RESULTS: Ultimately, there were 16 eligible studies pooled together, involving a total of 250 684 patients, including 231 552 CABG-naïve patients, and 19 132 patients with a prior history of CABG. Overall, patients with CABG history were associated with significantly greater short-term mortality ($P = .004$), long-term mortality ($P = .005$), myocardial infarction ($P < .00001$), major adverse cardiovascular events ($P = .0001$), and procedural perforation ($P < .00001$). Contrastingly, CABG-naïve patients were associated with significantly greater risk of cardiac tamponade ($P = .02$) and repeat CABG ($P = .03$). No significant differences in stroke, bleeding, revascularization, or repeat PCI were observed.

CONCLUSION: Comparatively worsened clinical outcomes were observed, as patients with prior CABG history typically exhibit complex coronary anatomy, and have higher rates of comorbidities in comparison to their CABG-naïve counterparts. The refinement of current procedural and surgical techniques, in conjunction with continued research endeavors, are needed in order to effectively address this trend.

KEYWORDS: Percutaneous coronary intervention, PCI, previous coronary artery bypass grafting, CABG, meta-analysis

Introduction

Percutaneous coronary intervention (PCI), also known as coronary angioplasty, is the preferred strategy for treating obstructive coronary artery disease, including acute myocardial infarction.[1,2] In view of the relentless advancing technology within the evolving field of interventional cardiology, the clinical outcomes and long-term durability of results have the potential to demonstrate excellence.[3] However, the risk of common complications still remains, such as bleeding, major adverse cardiovascular events (MACE), and death.[4] In addition, the use of contrast agents during the PCI procedure carries risk of nephrotoxicity, with patients subject to a risk of developing contrast-induced nephropathy.

The apprehension arises when a patient presents with a history of previous coronary artery bypass grafting (CABG) surgery. Numerous studies have consistently reported decreased rates of procedural success in comparison to those with an absent history of prior surgical revascularization. This discrepancy may be attributed to the complex coronary anatomy in such patients, and the frequent presence of severely calcified lesions in comparison to their CABG-naïve counterparts.[5]

There emerges a notable gap in the comprehensiveness of current existing literature, especially with regards to the short-term and long-term clinical outcomes of individuals who have undergone prior CABG. Consequently, it remains uncertain whether the lower procedural success rate can be quantifiably proven to translate into worsened clinical outcomes within a larger pooled sample population, and whether such results apply to the short-term duration, the long-term duration, or both. In light of these queries, this comprehensive systematic review and meta-analysis was conducted to explore both the short-term and long-term clinical outcomes of patients undergoing PCI, with or without the history of prior CABG. These results aim to consolidate and quantify our understanding

regarding this important controversy, and provide reliable, evidence-based clinical guidelines and recommendations in order to ensure the highest caliber of desirable post-procedural outcomes in patients undergoing PCI.

Methods

Data sources and search strategy

This systematic review and meta-analysis has been performed in conformity with the "Preferred Reporting Items for Systematic Review and Meta-Analysis" (PRISMA) guidelines.[6] A comprehensive systematic search was conducted on electronic databases including PubMed/MEDLINE, Cochrane Library, and ScienceDirect from inception to September 1, 2023. In addition, the bibliographies of potentially relevant studies were further searched for similar articles. The search strategy utilized for each database of interest is available on Supplemental Table 1. In order to utilize a rigorous methodology within this meta-analysis, an evaluation using the "Assessing the Methodological Quality of Systematic Reviews" (AMSTAR-2) guidelines was integrated.[7]

Study selection, eligibility criteria, and data extraction

All studies generated via the systematic search strategy were extracted and exported to EndNote Reference Library, version X8.1 (Clarivate Analytics) for further shortlisting and removal of duplicates. Subsequently, a title and abstract search was performed, followed by an in-depth full-text review by 2 independent investigators (M. O. L. and A. A.). A third investigator was invited to identify and resolve any discrepancies noted between the 2 independent investigators (A. R. S.).

A pre-specified eligibility criteria was established to ensure the inclusion of relevant studies within this systematic review and meta-analysis. All of the following conditions were required to be met, including (i) studies including patients with previous history of CABG, (ii) studies reporting clinical outcomes and angiographic characteristics on patients undergoing PCI, (iii) studies reporting at least 1 of the outcome of interest, and (iv) published studies that may be randomized, non-randomized, prospective, or retrospective in nature. Other article types, such as letters reporting unoriginal data, case reports, systematic reviews, and narrative reviews were excluded from further assessment. The following data was extracted from the included studies: (i) baseline clinical characteristics of included study populations, (ii) baseline angiographic characteristics of included study population, (iii) short-term mortality within 30 days, (iv) long-term mortality > 30 days, (v) postprocedural myocardial infarction (MI), (vi) postprocedural major adverse cardiovascular events (MACE), (vii) postprocedural stroke, (viii) bleeding, (ix) revascularization, (x) cardiac tamponade, (xi) repeat CABG, and (xii) repeat PCI.

Risk of bias assessment

The risk of bias and assessment of quality of included studies was performed by 2 independent reviewers (A. I. and M. O. L.) using the Newcastle-Ottawa Scale for Quality Assessment of Cohort Studies and the Cochrane Risk of Bias Tool for Randomized Controlled Trials.[8,9] All cohort studies were comprehensively evaluated and subsequently scored out of 9 points. Studies receiving ratings between 7 and 9 were classed as high quality with low risk of bias, studies receiving ratings between 4 and 6 were classed as moderate quality with moderate risk of bias, and studies receiving ratings equal to or below 3 were classed as low quality with high risk of bias. Furthermore, all randomized controlled trials were evaluated on basis of the following domains: (i) randomization process, (ii) deviations from intended interventions, (iii) missing outcome data, (iv) measurement of the outcome, and (v) selection bias within reported results. In case of any discrepancies, a third reviewer (A. R. S.) was invited to resolve any disputes between the evaluation(s) of the initial independent reviewers.

Statistical analysis

All meta-analyses were performed using Review Manager (RevMan version 5.3; Copenhagen: The Nordic Cochrane Center, The Cochrane Collaboration, 2014). All dichotomous outcomes were compared using odds ratios, whereas all continuous outcomes were compared using mean differences and standard deviation. Statistical significance was denoted in P-values of $<.05$ throughout this meta-analysis. Heterogeneity was evaluated using the Higgins I^2 tool, in which any values exceeding $I^2 = 50\%$ were considered to be significantly heterogeneous.[10] In cases of significant heterogeneity, sensitivity analysis using the leave-one-out method was performed in order to identify the source of heterogeneity. Subgroup analyses were performed in outcomes with a sufficient number of studies, based on short-term and long-term incidence of events. Short-term was defined as event incidence within or equal to 30 days, and long-term was defined as event incidence beyond 30 days.

Results

Literature search, characteristics of studies, and quality assessment

The initial search unveiled 8044 articles from inception up till September 01, 2023. After the removal of duplicate articles, there were 5623 articles remaining. Ultimately, after the employment of a comprehensive screening strategy on the remaining articles, there were a total of 16 studies eligible for inclusion within this qualitative and quantitative synthesis.[11-26] A total of 250 684 patients were pooled collectively, including 231 552 CABG-naïve patients (nCABG), and 19 132 patients with a prior history of CABG (pCABG). Out of the 16 included studies, there were 11 retrospective observational studies, 4 prospective observational studies, and a single RCT.
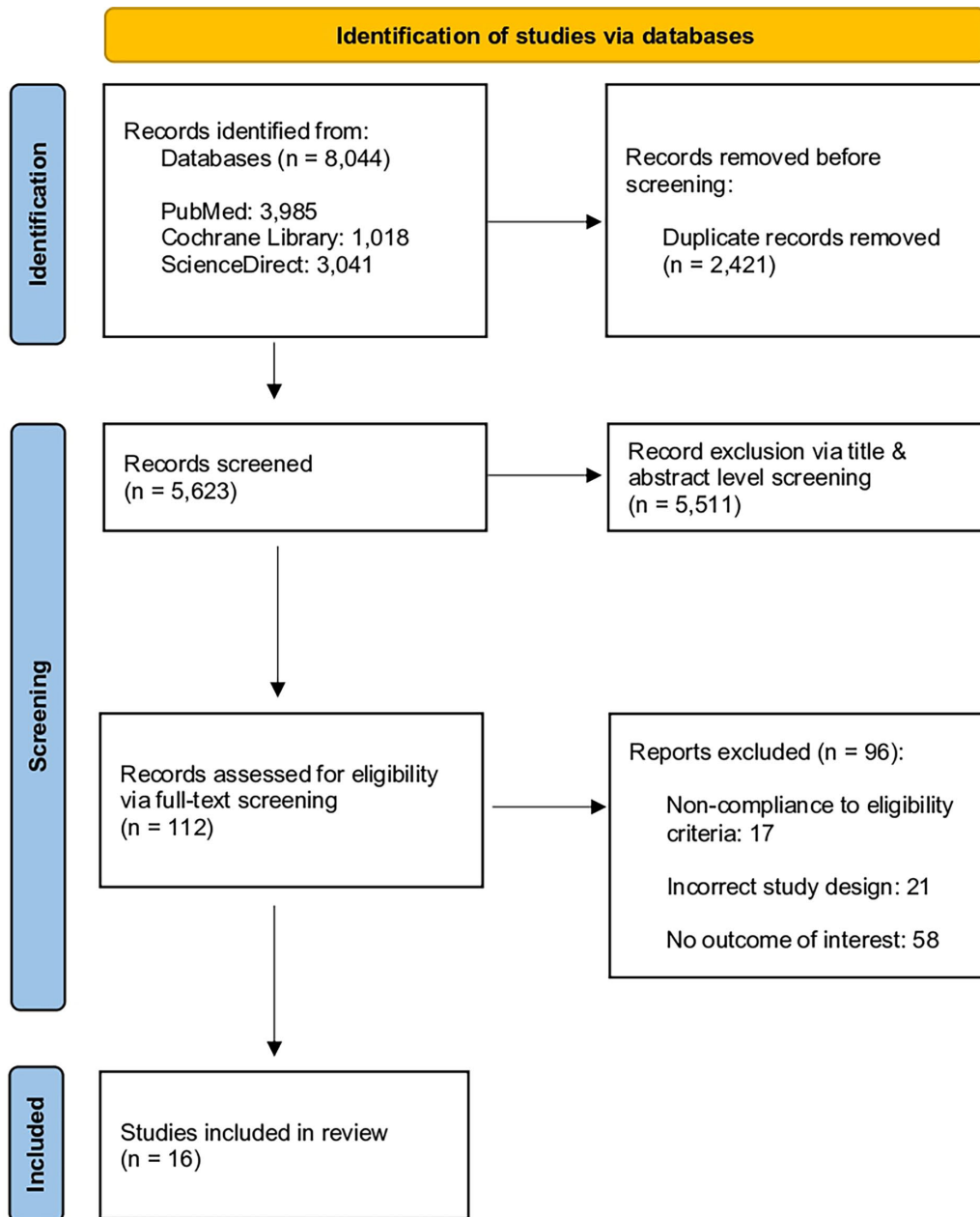
Identification of studies via databases

Identification

Records identified from:
Databases (n = 8,044)

PubMed: 3,985
Cochrane Library: 1,018
ScienceDirect: 3,041

Records removed before
screening:

Duplicate records removed
(n = 2,421)

Screening

Records screened
(n = 5,623)

Record exclusion via title &
abstract level screening
(n = 5,511)

Records assessed for eligibility
via full-text screening
(n = 112)

Reports excluded (n = 96):

Non-compliance to eligibility
criteria: 17

Incorrect study design: 21

No outcome of interest: 58

Included

Studies included in review
(n = 16)

Figure 1. The PRISMA flowchart illustrating the screening process.

All included studies were of low-to-moderate risk of bias and moderate-to-high quality as per the Newcastle-Ottawa scale for the included cohort studies, and Cochrane Risk of Bias tool for the included randomized controlled trials. Most included studies were rated ≥7, indicating a low risk of bias and high quality of assessment. The remaining studies demonstrated a moderate risk of bias and moderate quality of assessment. Complete details of the risk of bias assessment are available in Supplemental Tables 2 and 3.

The following outcomes were evaluated within this meta-analysis, including: (i) short-term mortality, (ii) long-term mortality, (iii) incidence of MI, (iv) incidence of MACE, (v) incidence of stroke, (vi) incidence of bleeding, (vii) revascularization, (viii) incidence of cardiac tamponade, (ix) procedural perforation, (x) need for repeat PCI, and (xi) need for subsequent CABG.

The comprehensive screening process is illustrated in the PRISMA flowchart in Figure 1. Detailed baseline clinical and angiographic characteristics of the included study population are available in Tables 1 and 2 respectively.

Comparison of mortality

Short-term mortality was reported by 11 studies (pCABG: 10,769 patients; nCABG: 211 895 patients), and was associated with a statistically significant increase in comparison to their counterparts with no history of prior CABG (OR: 1.62; 95% CI [1.17-2.26]; I^2 = 63%; P = .004; Figure 2). Long-term mortality was reported by 8 studies (pCABG: 7724 patients; nCABG: 198 291 patients), and was associated with a statistically significant increase in comparison to their counterparts

Table 1. Baseline characteristics of included study population.

STUDY TITLE	STUDY DESIGN	PARTICIPANTS, N		MEAN AGE, Y (SD)		MALE, N		MEAN BMI (SD)		DIABETES MELLITUS, N (%)	
		CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG
Yamaji et al[11]	Retrospective study	919	11 893	69.4 (9.0)	68.3 (10.4)	729 (79)	8914 (75)	23.7 (3.4)	24.0 (3.4)	452 (49)	4860 (41)
Iqbal et al[12]	Retrospective study	1490	76 637	67.3 (11.5)	63.3 (13.1)	-	-	-	-	279 (20)	9733 (13)
Toma et al[13]	Retrospective study	292	1710	68.0 (9.0)	65.0 (11.0)	-	-	28.5 (4.4)	28.1 (4.4)	113 (39)	477 (28)
Azzalini et al[14]	Retrospective study	401	1657	69.2 (8.0)	64.3 (10.6)	366 (92)	1444 (87)	28.8 (5.1)	28.6 (7.3)	191 (48)	579 (35)
Garg et al[15]	Retrospective study	47	2086	64.8 (10.0)	62.7 (12.8)	39 (83)	1525 (73)	-	-	5 (11)	232 (11)
Rathod et al[16]	Prospective study	8938	111 139	67.8 (10.2)	63.7 (12.4)	82 576 (74)	2472 (87)	-	-	3155 (35)	24 895 (22)
Mathew et al[17]	Retrospective study	1431	4629	67.1 (9.9)	64.8 (12.0)	1123 (79)	3043 (66)	-	-	407 (29)	923 (20)
Teramoto et al[18]	Retrospective study	153	1139	68.2 (9.1)	66.0 (11.5)	82 (54)	932 (82)	-	-	65 (42)	427 (37)
Al Suwaidi et al[19]	Retrospective study	128	944	69.3 (9.1)	63.8 (12.4)	96 (75)	639 (68)	-	-	38 (30)	192 (20)
Sen et al[20]	Prospective study	202	1507	68.5 (9.4)	64.1 (10.7)	161 (80)	1072 (71)	-	-	58 (29)	315 (21)
Santiago et al[21]	Retrospective study	35	258	65.0 (6.0)	62.0 (12.0)	27 (77)	186 (72)	-	-	-	-
Alexandrou et al[22]	Retrospective study	3475	8689	67.7 (33.8)	63.6 (23.3)	2844 (85)	6741 (80)	30.3 (5.8)	30.5 (6.4)	1681 (51)	3303 (39)
Welsh et al[23]	Randomized controlled trial	128	5617	69.0 (13.2)	61 (14.2)	110 (86)	4311 (77)	-	-	32 (25)	187 (16)
Budassi et al[24]	Prospective study	217	1035	68.5 (8.5)	64.9 (10.7)	187 (86)	885 (86)	28.3 (3.9)	28.5 (4.8)	68 (31)	264 (26)
Dautov et al[25]	Prospective study	175	295	70.0 (7.0)	64.0 (11.0)	150 (86)	226 (77)	29.0 (5.0)	30.0 (6.0)	87 (52)	86 (30)
Tajti et al[26]	Retrospective study	1101	2317	67.3 (9.3)	63.3 (10.2)	958 (87)	1946 (84)	30.6 (5.8)	30.7 (6.3)	539 (49)	903 (39)

Abbreviations: BMI, body mass index; CABG, coronary artery bypass grafting; CAD, coronary artery disease; n, number of participants; PCI, percutaneous coronary intervention; SD, standard deviation; y, years.

with no history of prior CABG (OR: 1.81; 95% CI [1.54-2.12]; $I^2 = 66\%$; $P = .005$; Figure 2).

Comparison of MI, MACE, and stroke

Postprocedural MI was reported by 11 studies (pCABG: 9198 patients; nCABG: 110 295 patients), and was associated with a statistically significant increase in patients with CABG history when compared to their counterparts with no history of prior

CABG (OR: 1.80; 95% CI [1.55-2.09]; $P < .00001$; Figure 3). There were no statistically significant subgroup differences observed between short-term and long-term events of postprocedural MI ($P = .20$). Postprocedural MACE was reported by 9 studies (pCABG: 8739 patients; nCABG: 195 764 patients), and was associated with a statistically significant increase in patients with CABG history when compared to their counterparts with no history of prior CABG (OR: 1.36; 95% CI [1.16-1.59]; $P = .0001$; Figure 4). There were no statistically

HYPERTENSION, N (%)		DYSLIPIDEMIA, N (%)		SMOKING, N (%)		FAMILY HISTORY OF CAD, N (%)		PREVIOUS PCI, N (%)		ANTIPLATELET THERAPY	
CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG
696 (76)	8854 (75)	-	-	87 (10)	2517 (21)	-	-	564 (61)	5381 (45)	-	-
750 (51)	29757 (39)	727 (50)	29368 (39)	855 (67)	46429 (68)	489 (40)	24220 (37)	150 (10)	8084 (11)	Glycoprotein IIb/IIIa: 716 (53.4)	Glycoprotein IIb/IIIa: 36831 (54.5)
262 (90)	1385 (81)	265 (91)	1461 (85)	19 (7)	382 (22)	118 (40)	630 (37)	68 (23)	242 (14)	-	-
345 (87)	1215 (74)	362 (91)	1285 (78)	45 (12)	495 (31)	-	-	291 (73)	961 (58)	-	-
20 (43)	623 (30)	22 (47)	787 (38)	11 (23)	696 (33)	11 (23)	385 (18)	11 (23)	136 (6)	-	-
6114 (68)	60904 (55)	6355 (71)	78353 (71)	6239 (60)	66572 (60)	-	-	4308 (48)	26896 (24)	Glycoprotein IIb/IIIa: 4219 (47.2)	Glycoprotein IIb/IIIa: 27118 (24.4)
888 (63)	2535 (55)	855 (67)	2067 (52)	150 (11)	984 (21)	-	-	343 (24)	648 (14)	Abciximab: 232 (16.2) Warfarin: 331 (23.2)	Abciximab: 652 (14.1) Warfarin: 522 (11.3)
91 (59)	690 (61)	54 (35)	423 (37)	28 (18)	284 (25)	15 (10)	138 (12)	-	-	-	-
76 (60)	464 (50)	70 (61)	359 (47)	-	-	36 (37)	211 (30)	-	-	Abciximab: 24 (18.8)	Abciximab: 176 (18.6)
113 (56)	845 (56)	143 (72)	853 (58)	22 (11)	388 (26)	108 (60)	734 (52)	81 (40)	299 (20)	DAPT: 196 (97.0)	DAPT: 1479 (99.5)
-	-	-	-	-	-	-	-	-	-	-	-
3122 (94)	7262 (86)	3122 (94)	6855 (81)	584 (18)	2489 (30)	983 (37)	2151 (30)	2350 (73)	4790 (57)	-	-
90 (70)	2749 (49)	-	-	-	-	-	-	32 (37)	881 (9)	Aspirin: (85.2) Thienopyridine: (85.9)	Aspirin: (69.6) Thienopyridine: (25.6)
157 (72)	614 (59)	170 (78)	670 (65)	16 (7)	255 (25)	-	-	135 (63)	579 (56)	-	-
158 (93)	217 (75)	-	-	10 (7)	-	-	-	133 (76)	197 (67)	-	-
1032 (94)	2039 (88)	1049 (95)	2062 (89)	226 (21)	691 (30)	436 (40)	723 (31)	810 (74)	1393 (60)	-	-

significant subgroup differences observed between short-term and long-term events of postprocedural MACE (*P* = .47). Postprocedural stroke was reported by 8 studies (pCABG: 7439 patients; nCABG: 102 339 patients), where no statistically significant associations were observed between patients with or without history of prior CABG (OR: 1.52; 95% CI [0.91-2.53]; *P* = .11; Figure 5). There were no statistically significant subgroup differences observed between short-term and long-term events of postprocedural stroke.

Comparison of bleeding and revascularization

Postprocedural bleeding was reported by 8 studies (pCABG: 10 778 patients; nCABG: 203 474 patients), where no statistically significant associations were observed between patients with or without history of prior CABG (OR: 1.12; 95% CI [0.87-1.45]; *P* = .38; Figure 6). Revascularization rates were reported by 6 studies (pCABG: 3275 patients; nCABG: 21 202 patients), where no statistically significant associations were

Table 2. Baseline angiographic characteristics of included study population.

STUDY TITLE	TARGET VESSEL									
	RIGHT CORONARY, N (%)		LEFT ANTERIOR DESCENDING, N (%)		LEFT CIRCUMFLEX, N (%)		MODERATE OR SEVERE CALCIFICATION, N (%)		ANTEGRADE WIRING, N	
	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG
Yamaji et al[11]	-	-	-	-	-	-	206 (15)	1580 (9)	-	-
Iqbal et al[12]	70 (5)	33222 (43)	37 (3)	34262 (45)	44 (3)	12094 (16)	-	-	-	-
Toma et al[13]	128 (44)	803 (47)	43 (15)	513 (30)	107 (37)	393 (23)	208 (71)	913 (53)	-	-
Azzalini et al[14]	210 (53)	816 (49)	83 (21)	515 (31)	102 (26)	322 (20)	237 (59)	657 (40)	135 (40)	921 (62)
Garg et al[15]	-	-	-	-	-	-	-	-	-	-
Rathod et al[16]	0 (0)	42455 (38)	0 (0)	58015 (52)	0 (0)	27340 (25)	-	-	-	-
Mathew et al[17]	-	-	-	-	-	-	-	-	-	-
Teramoto et al[18]	93 (45)	616 (43)	45 (22)	488 (34)	64 (31)	323 (22)	110 (53)	505 (36)	49 (28)	335 (30)
Al Suwaidi et al[19]	-	-	-	-	-	-	-	-	-	-
Sen et al[20]	66 (33)	550 (37)	35 (17)	835 (55)	60 (30)	461 (31)	-	-	-	-
Santiago et al[21]	9 (20)	120 (45)	9 (20)	116 (44)	4 (9)	30 (11)	-	-	-	-
Alexandrou et al[22]	1749 (53)	4453 (53)	539 (16)	2505 (30)	877 (27)	1350 (16)	2058 (64)	3120 (38)	2481 (72)	7493 (87)
Welsh et al[23]	19 (15)	1929 (34)	23 (18)	2901 (52)	10 (8)	593 (11)	-	-	-	-
Budassi et al[24]	146 (67)	612 (59)	18 (8)	272 (26)	49 (23)	151 (15)	168 (77)	561 (54)	124 (57)	873 (84)
Dautov et al[25]	83 (48)	182 (62)	18 (10)	55 (19)	51 (29)	45 (15)	100 (58)	109 (37)	-	-
Tajti et al[26]	619 (56)	1277 (55)	183 (17)	644 (28)	287 (26)	363 (17)	787 (72)	1017 (44)	833 (76)	1981 (86)

Abbreviations: BMS, bare metal stents; CABG, coronary artery bypass grafting; DEB, drug eluting balloons; DES, drug eluting stents; J-CTO, Japan-chronic total occlusion; n, number of participants; SD, standard deviation.

observed between patients with or without history of prior CABG (OR: 1.26; 95% CI [0.72-2.21]; $I^2 = 97\%$; $P = .42$; Figure 7).

Comparison of cardiac tamponade and perforation

Postprocedural cardiac tamponade was reported by 3 studies (pCABG: 1697 patients; nCABG: 4317 patients), and was associated with a statistically significant rise in CABG-naïve patients, in comparison to their counterparts with CABG history (OR: 0.24; 95% CI [0.07-0.79]; $P = .02$; Figure 8). Procedural perforation was reported by 3 studies (pCABG: 4082 patients; nCABG: 11777 patients), and was associated with a statistically significant rise in comparison to their counterparts with no history of prior CABG (OR: 1.89; 95% CI [1.52-2.35]; $P < .00001$; Figure 8).

Comparison of subsequent CABG and repeat PCI

The need for subsequent CABG was reported by 5 studies (pCABG: 80272 patients; nCABG: 27239 patients), and was associated with a statistically significant increase in CABG-naïve patients, in comparison to their counterparts with CABG history (OR: 0.70; 95% CI [0.51-0.96]; $P = .03$; Figure 9). The need for repeat PCI was reported by 4 studies (pCABG: 79353 patients; nCABG: 15346 patients), where no statistically significant associations were observed between patients with or without history of prior CABG (OR: 1.29; 95% CI [0.99-1.70]; $P = .06$; Figure 9).

ANTEGRADE DISSECTION AND RE-ENTRY, N		RETROGRADE WIRING, N		MEAN J-CTO SCORE (SD)		STENT TYPE		RADIAL APPROACH, N (%)		FEMORAL APPROACH, N (%)	
CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG	CABG	NON-CABG
-	-	-	-	-	-	Sirolimus-eluting stent: 1241 (91)	Sirolimus-eluting stent: 16 307 (89)	-	-	-	-
-	-	-	-	-	-	DES: 709 (50.0)	DES: 42 236 (57.2)	428 (30.7)	36 272 (49.6)	968 (69.3)	36 849 (50.4)
-	-	122 (42)	354 (21)	-	-	DES: 205 (70) BMS: 8 (3) DEB: 3 (1)	DES: 1349 (79) BMS: 66 (4) DEB: 4 (0.2)	-	-	-	-
66 (20)	228 (15)	31 (9)	147 (10)	2.3 (1.2)	1.7 (1.2)	DES: 312 (97) Bioresorbable scaffolds: 4 (1.2) BMS: 5 (1.5) DEB: 2 (0.6) Balloon angioplasty: 0 (00	DES: 1301 (89) Bioresorbable scaffolds: 123 (8) BMS: 26 (1.8) DEB: 8 (0.5) Balloon angioplasty: 4 (0.3)	92 (23)	422 (26)	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	DES: 7588 (84.9)	DES: 101 692 (91.5)	90 (10.1)	36 898 (33.2)	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	82 (47)	300 (37)	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	DES: 35 (100)	DES: 258 (100)	-	-	35 (100)	258 (100)
162 (5)	290 (3)	774 (23)	745 (9)	2.8 (1.2)	2.2 (1.3)						
-	-	-	-	-	-	-	-	-	-	-	-
51 (24)	240 (23)	127 (59)	294 (28)	2.9 (1.2)	2.1 (1.2)	-	-	21 (9.7)	138 (13.3)	-	-
-	-	-	-	2.5 (1.3)	2.1 (1.2)	DES: 175 (100)	DES: 295 (100)	12 (7)	33 (11)	5 (3)	6 (2)
384 (35)	649 (28)	583 (53)	693 (30)	2.9 (1.2)	2.2 (1.3)	-	-	397 (36.1)	1024 (44.2)	986 (89.6)	1757 (75.8)

Assessment of heterogeneity

Significant heterogeneity ($I^2 \geqslant 50\%$) was observed in the following outcomes: (i) short-term mortality, (ii) long-term mortality, and (iii) revascularization. The use of sensitivity analysis was successful in significantly reducing the heterogeneity in short-term mortality and long-term mortality by the exclusion of Rathod et al,[16] leading the decrease of heterogeneity to $I^2 = 29\%$ (Supplemental Figure 1) and $I^2 = 0\%$ respectively (Supplemental Figure 2). Sensitivity analysis could not effectively resolve the heterogeneity observed in the revascularization rates.

Discussion

To the best of our knowledge, this comprehensive systematic review and meta-analysis is the first study to compare the clinical outcomes between all patients, irrespective of the type of disease, with previous CABG versus patients with no prior history of CABG (also known as CABG-naïve patients). A total of 16 studies complied with our rigid eligibility criteria and were subsequently included within the quantitative synthesis, resulting in the pooling of 250 684 patients.[11-26] In summary, patients with previous history of CABG were significantly associated with a higher rate of short-term mortality, long-term mortality, postprocedural MI, postprocedural MACE, and procedural perforation. In contrast, CABG-naïve patients were associated with a significantly higher incidence of cardiac tamponade and rates of repeat CABG. No statistically significant differences in postprocedural stroke, bleeding, revascularization, or repeat PCI were observed.
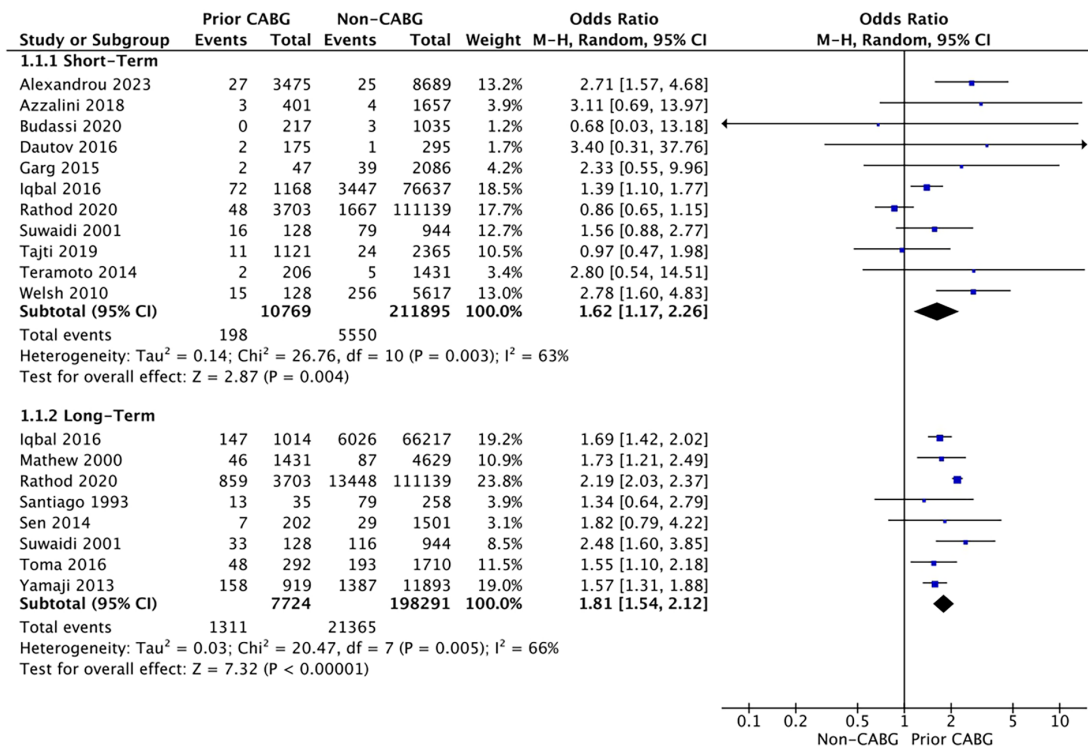
Figure 2. Forest plot of short-term and long-term mortality.
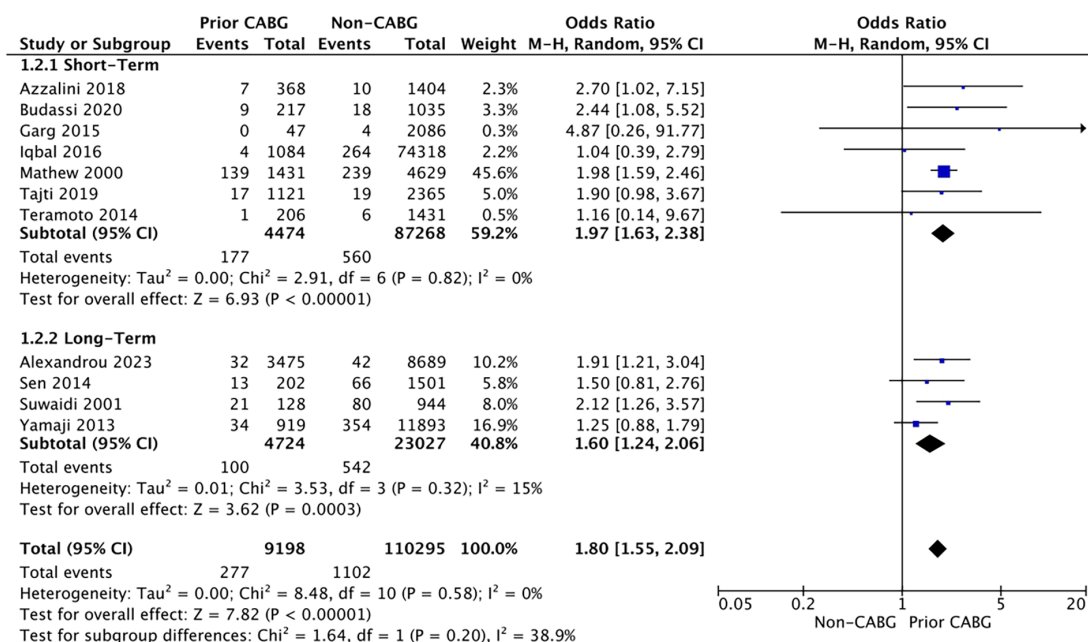
Figure 3. Forest plot of postprocedural myocardial infarction (MI).

Patients who have been subjected to previous surgical revascularization are known to be at greater risk than their counterparts.[27,28] The greater age, higher frequency of the male gender, and sizeable presence of comorbidities account for the worsened results observed within our meta-analysis. Moreover, patients with prior CABG surgery often present with complex coronary anatomy, a consequence of the intricate coronary atherosclerosis that necessitated the initial CABG procedure and

the potential acceleration of coronary atherosclerosis development due to CABG itself.[29] Furthermore, patients with a history of CABG have been observed to develop features of a more aggressive atherosclerotic disease in comparison to chronic total occlusion (CTO) in CABG-naïve patients,[30] including more offensive calcification and moderate negative remodeling. Resultantly, CABG patients have also been known to experience worsened procedural and technical metrics,

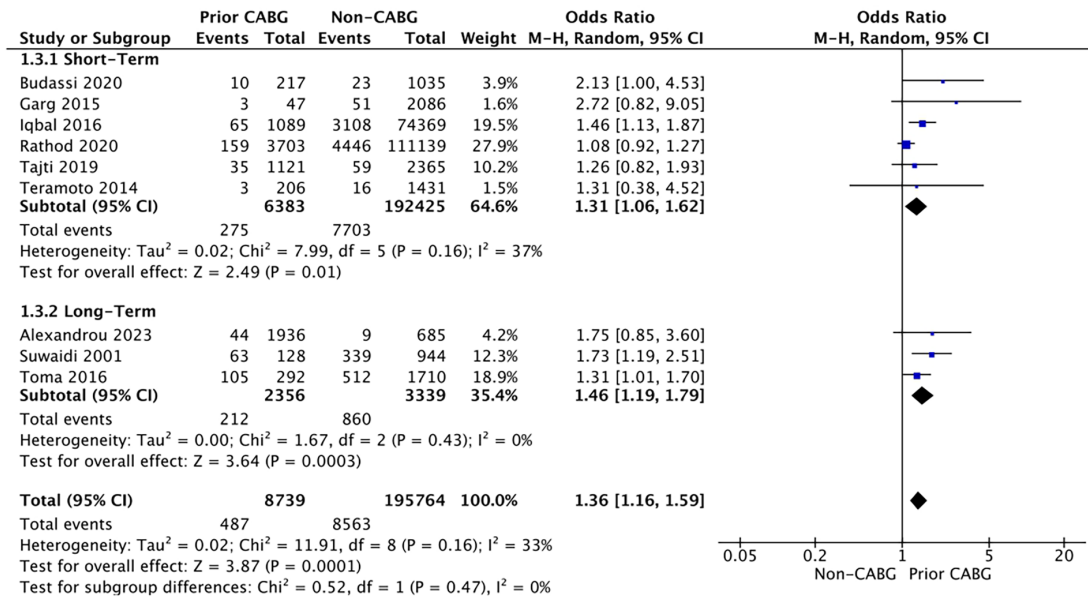|	Prior CABG		Non-CABG			Odds Ratio	
Study or Subgroup	**Events**	**Total**	**Events**	**Total**	**Weight**	**M-H, Random, 95% CI**	**M-H, Random, 95% CI**
1.3.1 Short-Term							
Budassi 2020	10	217	23	1035	3.9%	2.13 [1.00, 4.53]	
Garg 2015	3	47	51	2086	1.6%	2.72 [0.82, 9.05]	
Iqbal 2016	65	1089	3108	74369	19.5%	1.46 [1.13, 1.87]	
Rathod 2020	159	3703	4446	111139	27.9%	1.08 [0.92, 1.27]	
Tajti 2019	35	1121	59	2365	10.2%	1.26 [0.82, 1.93]	
Teramoto 2014	3	206	16	1431	1.5%	1.31 [0.38, 4.52]	
Subtotal (95% CI)		**6383**		**192425**	**64.6%**	**1.31 [1.06, 1.62]**	
Total events	275		7703				
Heterogeneity: Tau² = 0.02; Chi² = 7.99, df = 5 (P = 0.16); I² = 37%							
Test for overall effect: Z = 2.49 (P = 0.01)							
1.3.2 Long-Term							
Alexandrou 2023	44	1936	9	685	4.2%	1.75 [0.85, 3.60]	
Suwaidi 2001	63	128	339	944	12.3%	1.73 [1.19, 2.51]	
Toma 2016	105	292	512	1710	18.9%	1.31 [1.01, 1.70]	
Subtotal (95% CI)		**2356**		**3339**	**35.4%**	**1.46 [1.19, 1.79]**	
Total events	212		860				
Heterogeneity: Tau² = 0.00; Chi² = 1.67, df = 2 (P = 0.43); I² = 0%							
Test for overall effect: Z = 3.64 (P = 0.0003)							
Total (95% CI)		**8739**		**195764**	**100.0%**	**1.36 [1.16, 1.59]**	
Total events	487		8563				
Heterogeneity: Tau² = 0.02; Chi² = 11.91, df = 8 (P = 0.16); I² = 33%							
Test for overall effect: Z = 3.87 (P = 0.0001)							
Test for subgroup differences: Chi² = 0.52, df = 1 (P = 0.47), I² = 0%							

0.05 0.2 1 5 20
Non-CABG Prior CABG

Figure 4. Forest plot of postprocedural major adverse cardiovascular events (MACE).

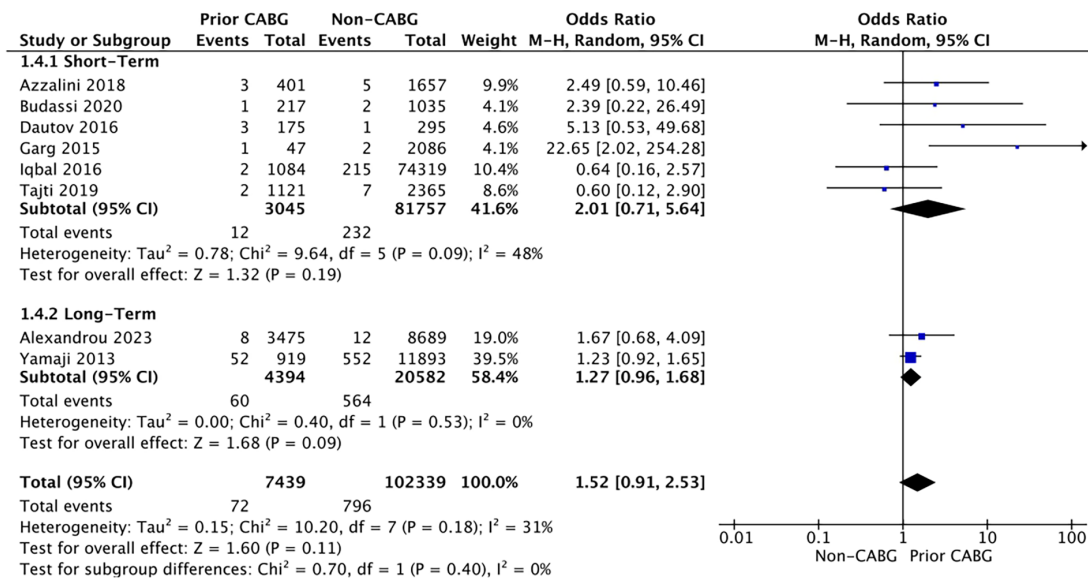|	Prior CABG		Non-CABG			Odds Ratio	
Study or Subgroup	**Events**	**Total**	**Events**	**Total**	**Weight**	**M-H, Random, 95% CI**	**M-H, Random, 95% CI**
1.4.1 Short-Term							
Azzalini 2018	3	401	5	1657	9.9%	2.49 [0.59, 10.46]	
Budassi 2020	1	217	2	1035	4.1%	2.39 [0.22, 26.49]	
Dautov 2016	3	175	1	295	4.6%	5.13 [0.53, 49.68]	
Garg 2015	1	47	2	2086	4.1%	22.65 [2.02, 254.28]	
Iqbal 2016	2	1084	215	74319	10.4%	0.64 [0.16, 2.57]	
Tajti 2019	2	1121	7	2365	8.6%	0.60 [0.12, 2.90]	
Subtotal (95% CI)		**3045**		**81757**	**41.6%**	**2.01 [0.71, 5.64]**	
Total events	12		232				
Heterogeneity: Tau² = 0.78; Chi² = 9.64, df = 5 (P = 0.09); I² = 48%							
Test for overall effect: Z = 1.32 (P = 0.19)							
1.4.2 Long-Term							
Alexandrou 2023	8	3475	12	8689	19.0%	1.67 [0.68, 4.09]	
Yamaji 2013	52	919	552	11893	39.5%	1.23 [0.92, 1.65]	
Subtotal (95% CI)		**4394**		**20582**	**58.4%**	**1.27 [0.96, 1.68]**	
Total events	60		564				
Heterogeneity: Tau² = 0.00; Chi² = 0.40, df = 1 (P = 0.53); I² = 0%							
Test for overall effect: Z = 1.68 (P = 0.09)							
Total (95% CI)		**7439**		**102339**	**100.0%**	**1.52 [0.91, 2.53]**	
Total events	72		796				
Heterogeneity: Tau² = 0.15; Chi² = 10.20, df = 7 (P = 0.18); I² = 31%							
Test for overall effect: Z = 1.60 (P = 0.11)							
Test for subgroup differences: Chi² = 0.70, df = 1 (P = 0.40), I² = 0%							

0.01 0.1 1 10 100
Non-CABG Prior CABG

Figure 5. Forest plot of postprocedural stroke.

owing to their angiographic complexities, subjecting them to frequent use of the retrograde approach and a worsened procedural success rate.[5,14] Furthermore, previous studies have magnified the worsened clinical outcomes of PCI in patients with CABG history in comparison to CABG-naïve patients.[16,23] As mentioned previously, the multitude of comorbidities and the severe presentation of CABG patients can create a significant challenge in their successful treatment, although they require careful procedural planning in consideration of their complex vascular anatomy.[26] In summary, the existing literature is concordant with the findings from our meta-analysis, with the consistent identification of the correlation between CABG history and the potential for increased risk of negative clinical outcomes, such as MACE or death.

There exists a sparseness of data comparing PCI on native vessels versus grafted vessels. Mathew et al compared the clinical outcomes of performing PCI on native vessels versus grafted vessels, which highlighted the diminished likelihood of death, MI, and repeat vascularization in those undergoing native-vessel PCI.[17] Although PCI on grafted vessels yields worsened clinical outcomes, it is still important to highlight that PCI of native vessels in CABG patients still demonstrated worsened clinical outcomes in comparison to PCI in patients with no history of CABG nonetheless. In a more recent study conducted by Rathod et al,[16] one of the largest studies exploring the challenges of PCI on native versus graft vessels, it was observed that >70% of patients with prior CABG history required PCI on the grafted vessel. Moreover, it was noted that
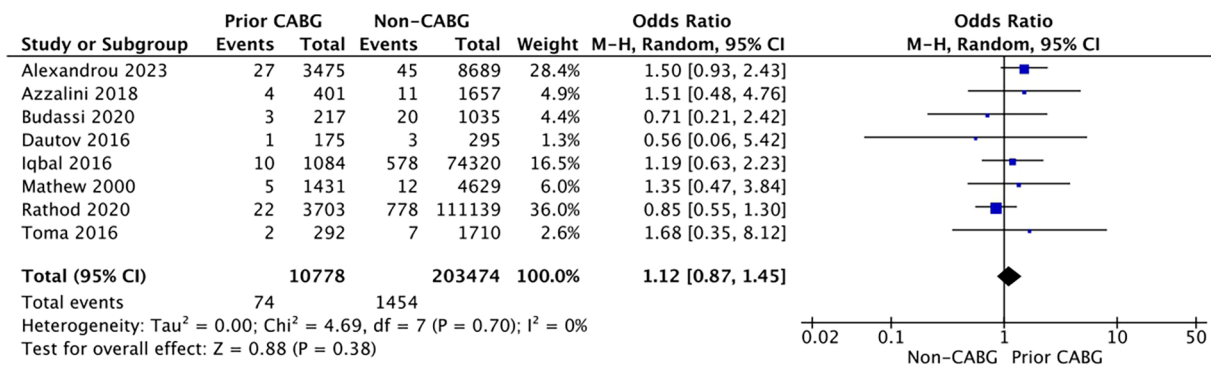
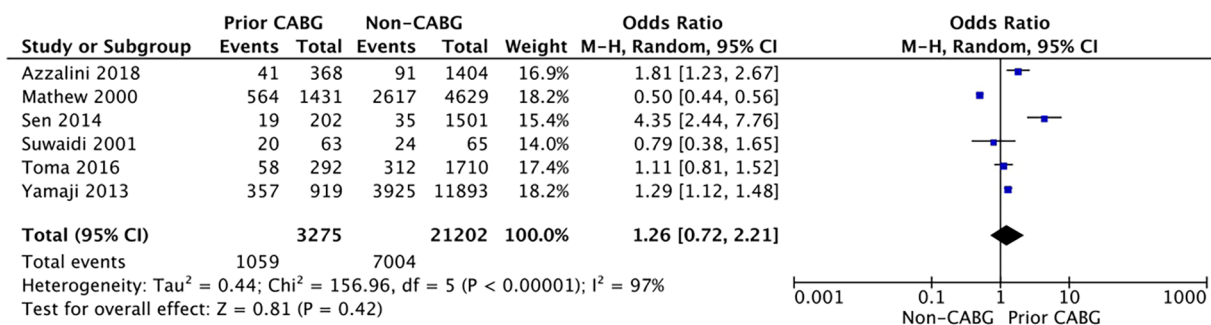**Figure 6.** Forest plot of postprocedural bleeding.

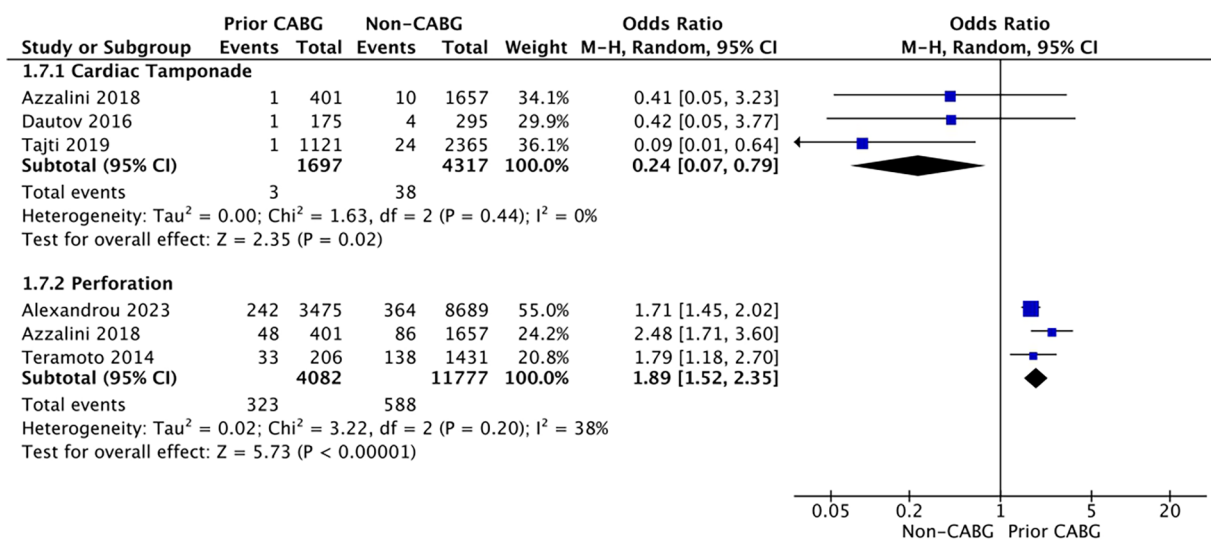**Figure 7.** Forest plot of revascularization.

Figure 8. Forest plot of postprocedural cardiac tamponade and procedural perforation.

the incidence of in-hospital events was comparable across all cohorts, although patients with PCI to a grafted vessel showed an elevated risk of mortality after discharge over time, even after adjustment for baseline characteristics, indicating that the initial success of the PCI procedure may not sustain itself through the long-term period. Additionally, several studies have highlighted the influence of presentation on the impact on the target lesion. Patients presenting with non-ST elevation myocardial infarction (STEMI) were more likely to be subject to a PCI of a grafted vessel, whereas patients presenting with stable angina were more likely to be subject to a PCI of the native vessel, identifying the type of presentation as a hallmark and predictor for the type of vessel requiring revascularization.[31,32] Therefore, we may conclude that performing a PCI on grafted vessels results in undesirable clinical outcomes, yet performing a PCI on a native vessel in a CABG patient will still provide worsened clinical outcomes, albeit not as worse as the grafted vessel. However, due to the limited number of studies and the absence of any randomized controlled trials, focusing on specific regions (eg, the United States and the United
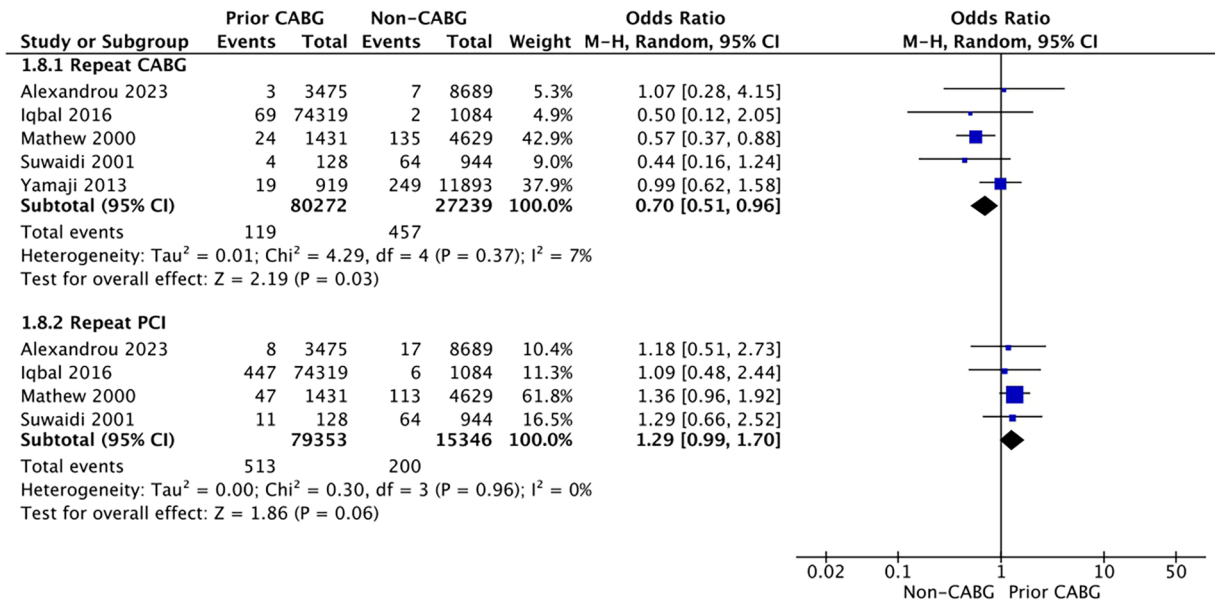
Study or Subgroup	Prior CABG Events	Total	Non-CABG Events	Total	Weight	Odds Ratio M–H, Random, 95% CI
1.8.1 Repeat CABG						
Alexandrou 2023	3	3475	7	8689	5.3%	1.07 [0.28, 4.15]
Iqbal 2016	69	74319	2	1084	4.9%	0.50 [0.12, 2.05]
Mathew 2000	24	1431	135	4629	42.9%	0.57 [0.37, 0.88]
Suwaidi 2001	4	128	64	944	9.0%	0.44 [0.16, 1.24]
Yamaji 2013	19	919	249	11893	37.9%	0.99 [0.62, 1.58]
Subtotal (95% CI)		80272		27239	100.0%	0.70 [0.51, 0.96]
Total events	119		457			

Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 4.29$, $df = 4$ ($P = 0.37$); $I^2 = 7\%$
Test for overall effect: $Z = 2.19$ ($P = 0.03$)

Study or Subgroup	Prior CABG Events	Total	Non-CABG Events	Total	Weight	Odds Ratio M–H, Random, 95% CI
1.8.2 Repeat PCI						
Alexandrou 2023	8	3475	17	8689	10.4%	1.18 [0.51, 2.73]
Iqbal 2016	447	74319	6	1084	11.3%	1.09 [0.48, 2.44]
Mathew 2000	47	1431	113	4629	61.8%	1.36 [0.96, 1.92]
Suwaidi 2001	11	128	64	944	16.5%	1.29 [0.66, 2.52]
Subtotal (95% CI)		79353		15346	100.0%	1.29 [0.99, 1.70]
Total events	513		200			

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.30$, $df = 3$ ($P = 0.96$); $I^2 = 0\%$
Test for overall effect: $Z = 1.86$ ($P = 0.06$)

Figure 9. Forest plot of repeat coronary artery bypass grafting (CABG) and repeat percutaneous coronary intervention (PCI).

Kingdom), the need for comprehensive studies encompassing wider geographical inclusivity remains.

This meta-analysis featured 16 studies ranging across 2 decades, where significant changes have occurred in terms of treatment modalities and management strategies. Non-invasive imaging has witnessed noteworthy advancements, enabling the exact visualization of coronary composition and myocardial features, allowing precision-based medicine in order to employ proper therapeutic measures and morbidity evaluation.[33] Biomarkers play a pivotal role in diagnostic screening of myocardial disease, particularly in emergent cases. Sensitive serum markers, such as troponins, allow for myocardial damage detection and early identification of acute conditions. Novel inflammatory markers in the field of cardiovascular medicine, such as C-reactive protein or interleukins, have a developing role in the prediction of coronary artery disease morbidity, mortality, and progression.[34] More importantly, newer antiplatelet treatment strategies have emerged, namely the dual antiplatelet treatment (DAPT) strategy involving P2Y12 receptor drugs. These drugs have shown profound effectiveness in reducing MACE and other post-ACS complications.[35] The introduction of the novel drug-eluting stents, over the traditional bare metal stents, have contributed to majorly improved long-term follow-up outcomes post-PCI, especially mortality.[36] With the progression of time, further research advances are expected, with aims of ameliorating morbidity and mortality to an unprecedented degree.

Other periprocedural outcomes were also evaluated, namely cardiac tamponade and coronary artery perforation. Interestingly, the risk of cardiac tamponade was greater in non-CABG patients in comparison to patients with prior CABG (OR: 0.24; $P = .02$). Although all included studies highlighted a lower risk of tamponade in previous CABG patients, only one was able to prove a statistically significant association. A prior meta-analysis failed to demonstrate any significant differences in the incidence of cardiac tamponade in patients with history of prior CABG undergoing transcatheter aortic valve replacement.[37] Therefore, current literature is limited and consolidates the conflicted understanding regarding this matter, warranting further research before arriving at a conclusion. A potential reason for this finding may be the increased presence of pericardial adhesions in prior CABG patients, which may lead to the pathogenesis of an atypical localized cardiac tamponade in lieu of the typical presentation of a tamponade.[38] Contrastingly, the risk of coronary artery perforation was greater in patients with prior CABG in comparison to non-CABG patients (OR: 1.89; $P < .00001$). This finding is parallel with previous literature, which identified the statistically significant association of coronary perforation in patients with CABG history; although, was not significant in patients with PCI history.[39,40] Other risk factors associated with perforation include age, the female sex, and kidney disease.[39,41] Alternative justification may involve the presence of coronary calcifications and complex lesions, which further weaken the coronary vessel wall, resulting in a greater risk of perforation.[42] Another culprit may be the arterial remodeling due to smooth muscle changes, resulting in stiffer arterial walls and hence increasing the incidence of perforation. Although limited data exists with regards to whether perforation predominantly occurs in native or grafted vessels; clinicians and surgeons should be wary of this risk, as it may create an opportunity for further sequelae (eg, tamponade, mortality).

An important yet overlooked predictor of post-PCI clinical outcomes include the operator approach and expertise. In a large multi-center study, the clinical impact of changing the operator's usual approach was evaluated,[43] where it was observed that predominantly radial operators showed greater

mortality, stroke, and bleeding complications during femoral approach in angiography, and higher periprocedural mortality during femoral approach in PCI. Similar reservations were raised in a large-scale comparison of left radial approach versus right radial approach, where outcomes in the latter group may have potentially worsened due to operator experience.[44]

Significant levels of heterogeneity ($I^2 \geqslant 50\%$) were observed in the following outcomes of this analysis: (i) short-term mortality, (ii) long-term mortality, and (iii) revascularization rates. Through sensitivity analysis using the leave-one-out method, heterogeneity was reduced to a moderate level in short-term mortality, and eradicated completely in long-term mortality. This involved the exclusion of Rathod et al,[16] which may be explained by the inclusion of patients undergoing PCI on grafted vessels within this analysis, as opposed to the inclusion of a mixed patient population undergoing PCI on both grafted and native vessels. On the contrary, sensitivity analysis could not reduce or eradicate the significant level of heterogeneity present in the revascularization outcome, most likely attributed to the highly varied results observed in the list of included observational studies. Therefore, it is plausible to assume apprehension when interpreting the results of the outcome.

Clinical implications and future prospects

In the foreseeable future, several clinical implications and recommendations emerge with respect to this salient topic. Firstly, a personalized approach to patient management is imperative, with comprehensive pre-procedural assessments considering individual clinical history, comorbidities, and anatomical nuances. These efforts will aid in the identification of high-risk patients, and allow pre-procedural endeavors to reduce the risk of adverse clinical outcomes, while also encourage transparent informed consent. In addition, the exploration and refining of advanced surgical techniques, including minimally invasive procedures and innovative grafting approaches, holds promise for enhancing outcomes in this patient group. However, continuous research efforts are essential to better understand the multifactorial contributors to adverse outcomes in patients with CABG history, facilitating targeted therapeutic interventions. In summary, addressing these challenges require a multifaceted approach, grounded in advanced techniques, expertise, and research-driven strategies, aiming to enhance PCI outcomes in patients with a history of CABG.

Strengths and limitations

To the best of our knowledge, this systematic review and meta-analysis is the most expansive and provides contemporary information to existing literature by elucidating the gravity of worsened outcomes after PCI in patients with previous CABG history. This imparts the ability to arrive at well-informed, reliable, and evidence-based clinical decisions and recommendations based on the grounded conclusions of our meta-analysis. Moreover, the comprehensiveness of the quantitative synthesis paves an avenue for future researchers to further address this crucial subject, and potentially explore effective resolutions for underlying issues responsible for our findings. Furthermore, the pre-specified subgroup analyses for short-term and long-term outcomes provides a far deeper understanding on the magnitude of results, in lieu of simple quantitative comparisons who fail to provide practical insights.

Despite the agreeable strengths and undeniable power of our analysis, there were some limitations that must be highlighted. First, the exclusive inclusion of observational studies accounts for the tendency to cause bias and heterogeneity within our outcomes, as observed within the short-term mortality, long-term mortality, and revascularization. Additionally, most included studies were of retrospective nature, identified to have a notable incidence of selection bias, potentially skewing the results of our study.[45] Moreover, the failure of baseline and confounder adjustment in certain included studies resulted in the heightened aspect of bias and heterogeneity. Furthermore, it was noted that certain studies featured patient populations solely including CTO,[24-26] whereas other studies included a mixed population. Clinically, this may lead to a large variance within the incidence of poorer outcomes, and potentially impact the results of our analysis. Lastly, although the systematic review comprised of 3 prominent databases, the search cannot be labeled as exhaustive and boasts the possibility of missed publications, which may inadvertently affect the accuracy of the results generated.

Conclusion

In conclusion, this comprehensive meta-analysis highlighted the statistically significant association of prior CABG history with increased short-term mortality, long-term mortality, postprocedural MI, postprocedural MACE, and procedural perforation. In contrast, CABG-naïve patients were associated with a significantly higher incidence of cardiac tamponade and rates of repeat CABG. No significant differences in postprocedural stroke, bleeding, revascularization, or repeat PCI were observed. These results may be explained by the complex coronary vascular anatomy and the greater prevalence of comorbidities identified in such patients, as per existing literature. The refinement of current procedural and surgical techniques, in conjunction with continued research endeavors, are needed in order to effectively address this developing trend. However, future all-inclusive, exhaustive, and prospective studies are essential in order to arrive at a robust conclusion.

Author Contributions
MOL: Conceptualization, Formal analysis, Writing – original draft, Writing – review and editing, Supervision; AA: Formal analysis, Writing – original draft; ARS: Writing – original draft; HI: Writing – original draft; AI: Writing – original draft; MJ: Writing – review and editing, Supervision.

Ethical Approval
Not applicable.

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Supplemental Material
Supplemental material for this article is available online.

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