

Percutaneous Coronary Intervention at Centers With and Without On-Site Surgical Backup An Updated Meta-Analysis of 23 Studies

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Background—Emergency coronary artery bypass grafting for unsuccessful percutaneous coronary intervention (PCI) is now rare. We aimed to evaluate the current safety and outcomes of primary PCI and nonprimary PCI at centers with and without on-site surgical backup.

Methods and Results—We performed an updated systematic review and meta-analysis by using mixed-effects models. We included 23 high-quality studies that compared clinical outcomes and complication rates of 1 101 123 patients after PCI at centers with or without on-site surgery. For primary PCI for ST-segment–elevation myocardial infarction (133 574 patients), all-cause mortality (without on-site surgery versus with on-site surgery: observed rates, 4.8% versus 7.2%; pooled odds ratio [OR], 0.99; 95% confidence interval, 0.91–1.07; $P=0.729$; $I^2=3.4\%$) or emergency coronary artery bypass grafting rates (observed rates, 1.5% versus 2.4%; pooled OR, 0.76; 95% confidence interval, 0.56–1.01; $P=0.062$; $I^2=42.5\%$) did not differ by presence of on-site surgery. For nonprimary PCI (967 549 patients), all-cause mortality (observed rates, 1.6% versus 2.1%; pooled OR, 1.15; 95% confidence interval, 0.94–1.41; $P=0.172$; $I^2=67.5\%$) and emergency coronary artery bypass grafting rates (observed rates, 0.5% versus 0.8%; pooled OR, 1.14; 95% confidence interval, 0.62–2.13; $P=0.669$; $I^2=81.7\%$) were not significantly different. PCI complication rates (cardiogenic shock, stroke, aortic dissection, tamponade, recurrent infarction) also did not differ by on-site surgical capability. Cumulative meta-analysis of nonprimary PCI showed a temporal decrease of the effect size (OR) for all-cause mortality after 2007.

Conclusions—Clinical outcomes and complication rates of PCI at centers without on-site surgery did not differ from those with on-site surgery, for both primary and nonprimary PCI. Temporal trends indicated improving clinical outcomes in nonprimary PCI at centers without on-site surgery. (*Circulation*. 2015;132:388–401. DOI 10.1161/CIRCULATIONAHA.115.016137.)

Key Words: meta-analysis ■ mortality ■ onsite coronary artery bypass graft (CABG)
■ outcome assessment (health care) ■ percutaneous coronary intervention ■ STEMI ■ thoracic surgery

The need for emergency cardiac surgery has decreased dramatically from 6% to 10%,¹ during the era of balloon angioplasty, to 0.1% to 0.4% in the current era of stents because of the many advances in technology, techniques, adjunctive pharmacotherapy, and operator experience.^{2–4} Despite this progress, concerns remain about performing percutaneous coronary intervention (PCI) at centers without on-site surgical backup, especially regarding nonprimary PCI for conditions other than ST-segment–elevation myocardial infarction (STEMI). Because primary PCI confers longer survival and timely reperfusion, increased access to primary PCI was encouraged. Subsequently, numerous studies showed that safety and efficacy of primary PCI

are similar in centers with and without on-site surgical capability.^{4,5} Current American College of Cardiology Foundation/American Heart Association/Society for Cardiovascular Angiography and Interventions guidelines recommend that primary PCI for STEMI be performed at centers without on-site surgical backup (class IIa, level of evidence: B).^{1,5}

Editorial see p 365
Clinical Perspective on p 401

Conversely, nonprimary PCI has been a major issue in this debate; no survival benefit supports allowing nonprimary PCI at centers without on-site surgical backup. Nonprimary

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PCI without on-site surgical backup was regarded as class III (not recommended; potentially harmful); however, the 2011 American College of Cardiology Foundation/American Heart Association/Society for Cardiovascular Angiography and Interventions guideline changed this to a class IIb recommendation (level of evidence: B), but the guideline mandates stringent criteria for such a program.^{1,5} Furthermore, a previous meta-analysis, after adjusting for publication bias, indicated significantly higher mortality after nonprimary PCI at centers without on-site surgery.⁶ However, the current 2011 guideline and previous meta-analyses do not reflect very recent large-scale randomized, controlled trials of nonprimary PCI in centers without on-site surgery (eg, Cardiovascular Patient Outcomes Research Team Non-Primary PCI [CPORT-E] and Randomized Trial to Compare Percutaneous Coronary Intervention between Massachusetts Hospital with Cardiac Surgery On-Site and Community Hospitals without Cardiac Surgery On-Site [MASS COMM] trials) or large-scaled prospective registry data.^{2,3,7}

Therefore, we performed an updated meta-analysis of studies, including the most recent publications, to evaluate the safety and outcomes of primary PCI and nonprimary PCI at centers with and without on-site surgical backup.

Methods

The online-only Data Supplement describes study methods further.

Data Sources and Searches

PubMed, EMBASE, Cochrane Central Register of Controlled Trials, the US National Institutes of Health registry of clinical trials, and relevant websites were searched for pertinent published or unpublished studies. The electronic search strategy was complemented by manual examination of references cited by included articles, recent reviews, editorials, and meta-analyses. No restrictions were imposed on language, study period, or sample size.

Study Selection

Studies that met each of following criteria were considered eligible for meta-analysis: performed before February 2015; complications and clinical outcomes of PCI, including all-cause mortality or need of emergency surgery, from a center without on-site surgical backup were clearly reported; the outcomes were compared with a center with on-site surgical backup; for studies of primary PCI, a clear STEMI definition was reported; and had a randomized, controlled trial (RCT) or nonrandomized, prospective, observational study design. Eligible nonrandomized prospective observational studies adjusted appropriately for baseline differences between centers with or without on-site surgical backup (eg, propensity score-based adjustment, matching, or covariate adjustment). Studies that reported outcomes of PCI without a comparison or control group were not included.

Data Extraction and Quality Assessment

Summary data as reported in the published articles were analyzed. A standardized form was used to extract study characteristics, study design, number of study patients, type of PCI (primary or nonprimary), age, and clinical and angiographic eligibility criteria, including clinical diagnosis, definition of STEMI, proportion with 3-vessel disease or left main vessel intervention, and proportion of cardiovascular risk factors. The rates of all-cause mortality, in-hospital mortality, early mortality, late mortality, need for emergency surgery, complications related to PCI (stroke, cardiogenic shock, coronary dissection, cardiac tamponade, and recurrent myocardial infarction) were collected, along with the outcome definitions, as reported on an intention-to-treat basis. Patients with facilitated PCI or rescue PCI were not included in the STEMI group; such patients were likely to be included as non-STEMI patients in the nonprimary PCI group. For studies that enrolled both primary and nonprimary PCI patients, group size and number of events were separately extracted, according to the primary or nonprimary PCI category.

The quality of eligible studies was assessed by using the Cochrane Collaboration's tool for assessing the risk of bias for RCTs, the Newcastle-Ottawa Scale, and the strengthening the reporting of observational studies in epidemiology checklist for nonrandomized prospective observational studies. We did not exclude individual studies from the analysis based on thresholds of Newcastle-Ottawa Scale or strengthening the reporting of observational studies in epidemiology checklists.

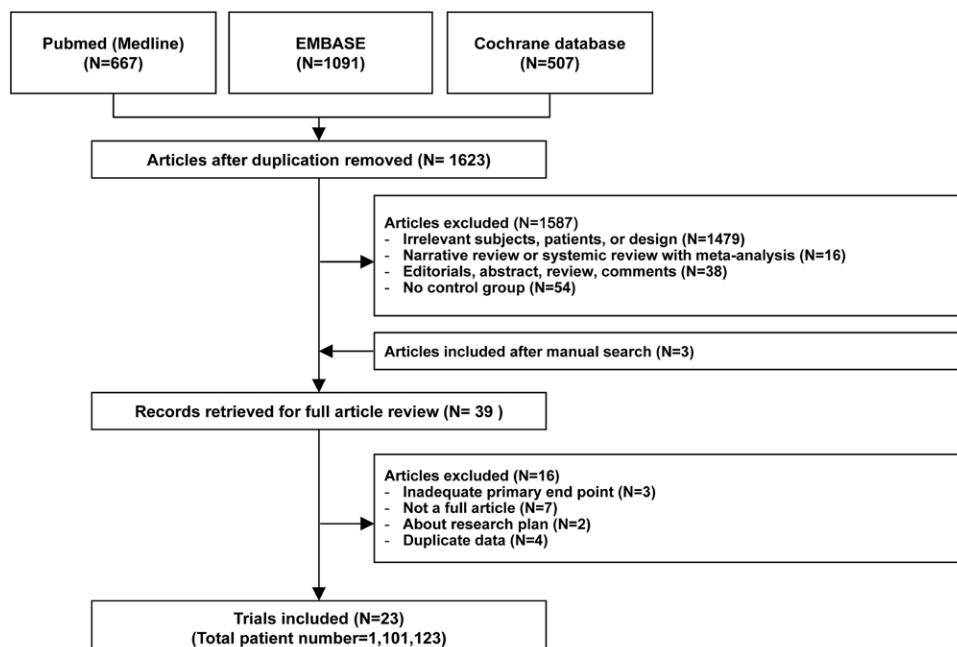


Figure 1. Flow diagram of study selection. The study flow diagram was depicted following the guideline of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). CABG indicates coronary artery bypass grafting.

Table. Characteristics of Included Studies

Source (Year)	Study Acronym	Study Period	Study Design	Indication for PCI	Follow-up Duration
Dellavalle et al (1995) ¹⁰	Dellavalle	1992–1994	Prospective registry	Nonprimary	30 d
Weaver et al (1995) ¹¹	MITI	1988–1994	Prospective registry	Primary	1 y
Sanborn et al (2004) ¹²	NRMI	1998–2001	Prospective registry	Primary	In-hospital
Singh et al (2004) ¹³	Mayo (ISJ-SMH)	2000–2002	Matched case-control	Both	In-hospital
Wennberg et al (2004) ¹⁴	Medicare	1999–2001	Prospective registry	Both	30 d
Wharton et al (2004) ¹⁵	Air PAMI-No SOS	1996–1999	RCT	Primary	30 d
Melberg et al (2006) ¹⁶	Norwegian RCT	1997–2001	RCT	Nonprimary	6 mo
Ting et al (2006) ¹⁷	Mayo (ISJ-SMH)	1999–2005	Matched case-control	Both	2 y
Carlsson et al (2006) ¹⁸	SCAAR	2000–2003	Prospective registry	Both	30 d
Peels et al (2007) ¹⁹	Alkmaar, The Netherlands	2002–2005	Prospective registry	Primary	30 d
Shiraishi et al (2007) ²⁰	AMI-Kyoto Multi-Center Risk Study	2000–2005	Prospective registry	Primary	In-hospital
Frutkin et al (2008) ²¹	MAHI	2003–2005	Prospective registry	Nonprimary	1 y
Pereira et al (2008) ²²	Portuguese NICR	2002–2006	Prospective registry	Both	In-hospital
Hannan et al (2009) ²³	PCIRS (New York)	2003–2006	Prospective registry	Primary	3 y
Kutcher et al (2009) ²⁴	NCDR	2004–2006	Prospective registry	Both	In-hospital
Pride et al (2009) ²⁵	NRMI-STEMI	2004–2006	Prospective registry	Primary	In-hospital
Pride et al (2009) ²⁶	NRMI-NSTEMI	2004–2006	Prospective registry	Nonprimary	In-hospital
Singh et al (2009) ²⁷	Mayo (ISJ-SMH)	1999–2007	Matched case-control	Both	In-hospital
Tebbe et al (2009) ²⁸	German, ALKK	1992–2006	Prospective registry	Both	In-hospital
Aversano et al (2012) ³	CPORT-E	2006–2011	RCT	Nonprimary	9 m
Jacobs et al (2013) ²	MASS COMM	2006–2011	RCT	Nonprimary	12 mo
Legutko et al (2014) ²⁹	EUROTRANSFER	2005–2007	Prospective registry	Primary	1 y
Maddox et al (2014) ⁷	VA-CART	2007–2010	Prospective registry	Both	1 y

ALKK indicates Arbeitsgemeinschaft; CPORT-E, Cardiovascular Patient Outcomes Research Team Non-Primary PCI; DM, diabetes mellitus; HTN, hypertension; ISJ, Immanuel St Joseph's Hospital; MAHI, Mid America Heart Institute; MASS COMM, The Randomized Trial to Compare Percutaneous Coronary Intervention between Massachusetts Hospitals with Cardiac Surgery On-Site and Community Hospitals without Cardiac Surgery On-Site; MI, myocardial infarction; MITI, Myocardial Infarction Triage and Intervention; NCDR, National Cardiovascular Data Registry; NR, not reported; NRMI, National Registry of Myocardial Infarction; NICR, National Interventional Cardiology Registry; NRMI, National Registry of Myocardial Infarction; NSTEMI, non-ST-segment-elevation myocardial infarction; PAMI-No SOS, No Surgery On-Site registry arm of the Air Primary Angioplasty in Myocardial Infarction; PCI, percutaneous coronary intervention; PCIRS, Percutaneous Coronary Intervention Reporting System; RCT, randomized, controlled trial; SCAAR, Swedish Coronary Angiography and Angioplasty Registry; SMH, Saint Mary's Hospital; STEMI, ST-segment-elevation myocardial infarction; VA-CART, The Veterans Affairs - Clinical Assessment, Reporting, and Tracking Program; and 3VD, 3-vessel disease.

Outcomes and Definitions

The primary outcome was the all-cause mortality rate at the longest available follow-up. Secondary outcomes included the need for emergency surgery related to the PCI; all-cause mortality stratified by time of death (definitions: early mortality occurred within 30 days of the index procedure and late mortality occurred after 30 days); and complications of PCI (stroke, cardiogenic shock, coronary dissection, cardiac tamponade, and recurrent myocardial infarction). If data were duplicated among studies, the most recent study was used.

Data Synthesis and Analysis

Primary and secondary outcomes were analyzed using mixed-effects models. Odds ratios (ORs) with 95% confidence intervals (CIs) were presented as summary statistics. Because all included studies showed heterogeneity regarding study protocol and populations, fixed-effects models were only used for sensitivity analyses to check whether these models yielded similar results. The pooled ORs and 95% CIs

were calculated by using the restricted maximum likelihood method for mixed-effects and the Mantel-Haenszel method for fixed effects.⁸ Because primary study designs and clinical practice patterns, especially revascularization methods (balloon angioplasty, bare metal stent, first- or second-generation drug-eluting stents [DES]), changed progressively, we evaluated the impact of the publication date on the overall pooled ORs for all-cause mortality rate by using cumulative meta-analysis. Cumulative meta-analysis updates the pooled estimate of the treatment effect each time the results of a new study are added. Therefore, cumulative meta-analysis repeats the pooled analysis whenever new studies become available for inclusion. Because all of the included studies in the cumulative meta-analysis had the same comparison groups, cumulative pooled-effect estimates up to the time point of last study inclusion could reflect temporal trends in effect size (OR).

All patients and outcomes were analyzed separately by type of PCI (primary PCI or nonprimary PCI) according to the originally assigned group. Statistical heterogeneity was quantified by using the

No. of Patients										
Primary PCI for STEMI		Nonprimary PCI for Other than STEMI		Demographics of Overall Population						
Without On-Site Surgery	With On-Site Surgery	Without On-Site Surgery	With On-Site Surgery	Age (mean)	Male, %	HTN, %	DM, %	Previous PCI, %	Previous MI, %	3VD, %
		199	164	59.9	78.7	NR	NR	13.9	55.2	7.1
470	592			60.1	75.6	NR	11.0	8.7	14.7	NR
1057	24890			62	71.3	47.8	18.4	14.5	16.9	NR
103	103	57	57	64	70.5	59.5	17.5	14.0	NR	51.5
1795	34537	6373	583149	NR	56.7	NR	24.5	NR	10.1	NR
499	71			63.8	71.6	51.0	19.5	NR	14.8	56.8
		305	304	58.5	79.5	24.5	7.0	7.5	39.0	25.0
722	722	285	285	64.9	68.0	69.0	24.0	34.0	36.5	61.5
857	4595	7981	20930	64.2	71.1	38.9	17.1	NR	38.2	16.9
336	103			64.2	71.8	33.9	8.7	8.2	9.8	NR
792	993			67.9	73.6	45.8	24.6	8.3	13.2	2.1
		1090	3317	66	67.7	75.8	32.5	47.0	37.3	37.7
1470	1214	5584	4831	63.5	75.5	64.2	25.0	16.4	37.6	49.0
1729	1729			59.5	74.9	NR	14.9	9.9	NR	11.2
1934	31099	6802	268312	64.1	66.0	74.9	31.9	34.9	28.9	NR
1655	1768			61.3	72.0	52.5	18.2	15.5	15.5	NR
		1237	1276	63.5	65.2	66.0	24.5	18.0	19.9	NR
667	667	1842	1842	64.4	68.0	70.8	26.0	31.2	26.3	45.7
5641	7371	4549	4565	67.8	71.5	NR	22.3	35.2	NR	25.5
		14149	4718	63.9	63.7	84.7	39.0	31.4	42.6	28.0
		2700	884	64.6	67.8	NR	31.8	28.6	23.1	1.1
654	996			64	72.2	NR	16.2	7.4	12.5	NR
412	1331	5517	14245	63	98.4	91.6	45.7	55.9	31.0	33.6

*I*² statistics. Publication bias, which is a known threat to the validity of meta-analysis and occurs when studies with statistically significant or clinically favorable results are more likely to be published than studies with nonsignificant or unfavorable results,⁹ was assessed by funnel plot asymmetry and the Egger and Begg tests; when visual asymmetry of the funnel plot was suspected, the trim-and-fill method was used to estimate the number of missing studies and to calculate a corrected OR, as if these studies were present. The influence of an individual study was explored by estimating pooled ORs, with stepwise exclusion of 1 study.

Subgroup analyses were performed to determine whether effects differed across subgroups. These subgroups analyses were analyzed: (1) study design (RCT or prospective observational study); (2) proportion with 3-vessel disease (proportion <30% or ≥30%); (3) second-generation DES era (before 2007 or after 2007); and (4) whether the study was multicenter or single center. Two-sided *P* values <0.05 were considered statistically significant. Statistical analysis was performed by using STATA/SE 12.0 (Stata Corp LP, College Station,

TX) and R programming language, version 3.1.1 (R Foundation for Statistical Computing, Vienna, Austria). The present study complied with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Table I in the online-only Data Supplement) and the Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines. The review protocol has not been registered.

Results

Search Results

We identified 2265 citations. Among these citations, 39 articles were retrieved for full review; 23 met inclusion criteria (Figure 1).^{2,3,7,10-29} Characteristics of the 16 excluded studies, after full-article review, are summarized in the online-only Data Supplement. The final 23 studies included 1101123 patients;

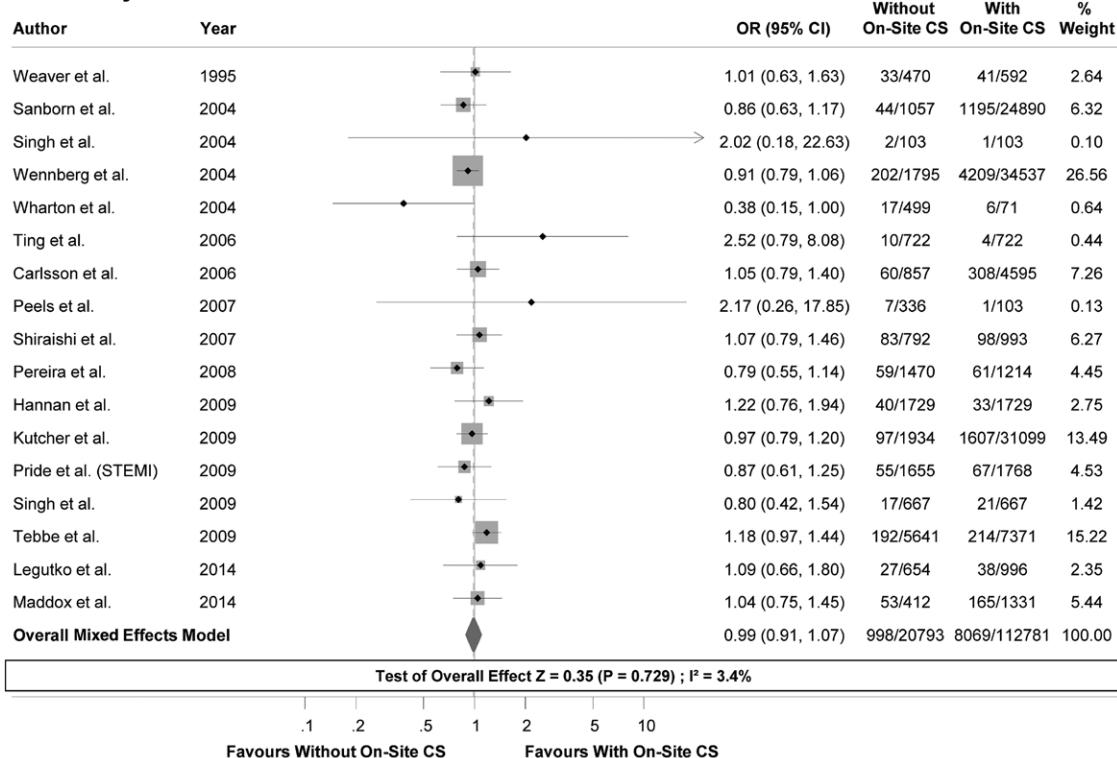
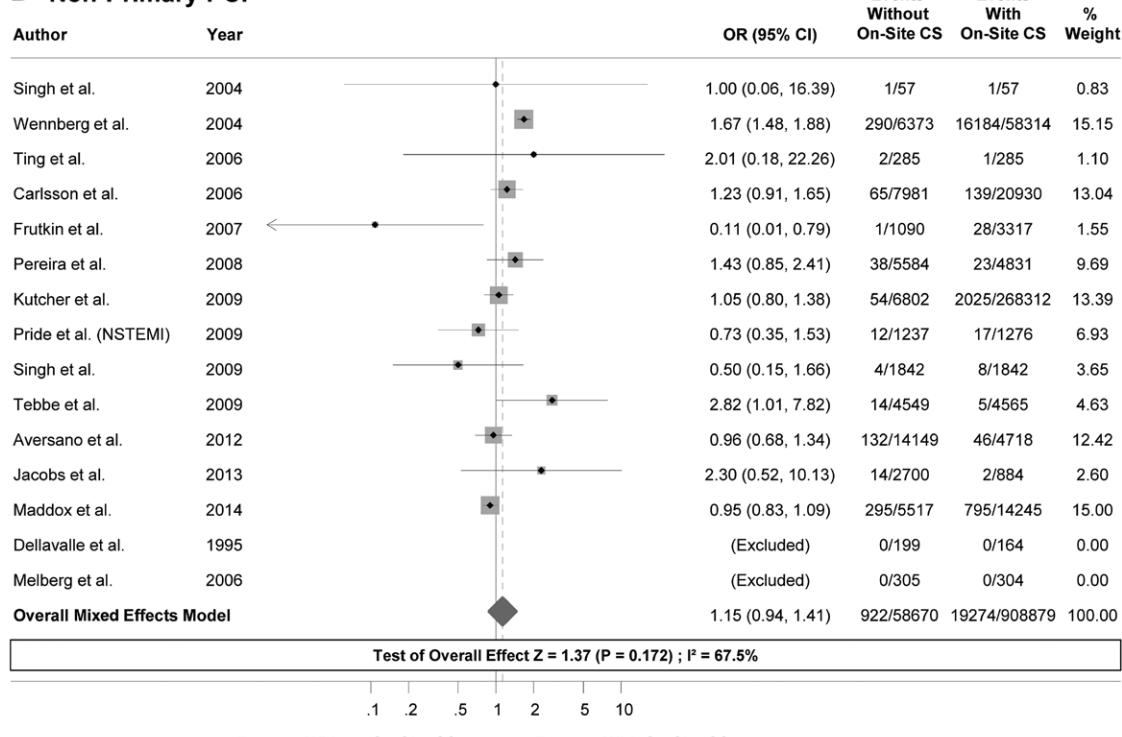
A Primary PCI**B Non-Primary PCI**

Figure 2. Forest plots comparing all-cause mortality after PCI at centers with or without on-site surgery. ORs with 95% CIs are displayed for individual studies and the pooled overall effect. **A**, Primary PCI. **B**, Nonprimary PCI. CI indicates confidence interval; CS, cardiac surgery; OR, odds ratio; NSTEMI, non-ST-segment-elevation myocardial infarction; PCI, percutaneous coronary intervention; and STEMI, ST-segment-elevation myocardial infarction.

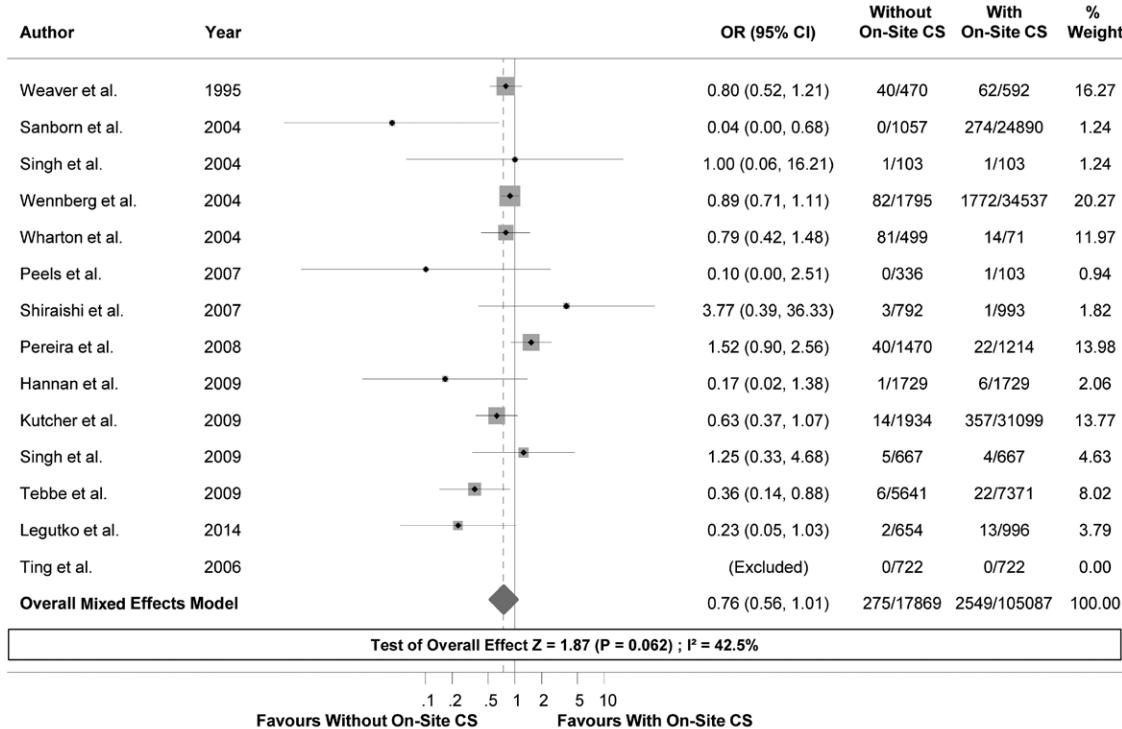
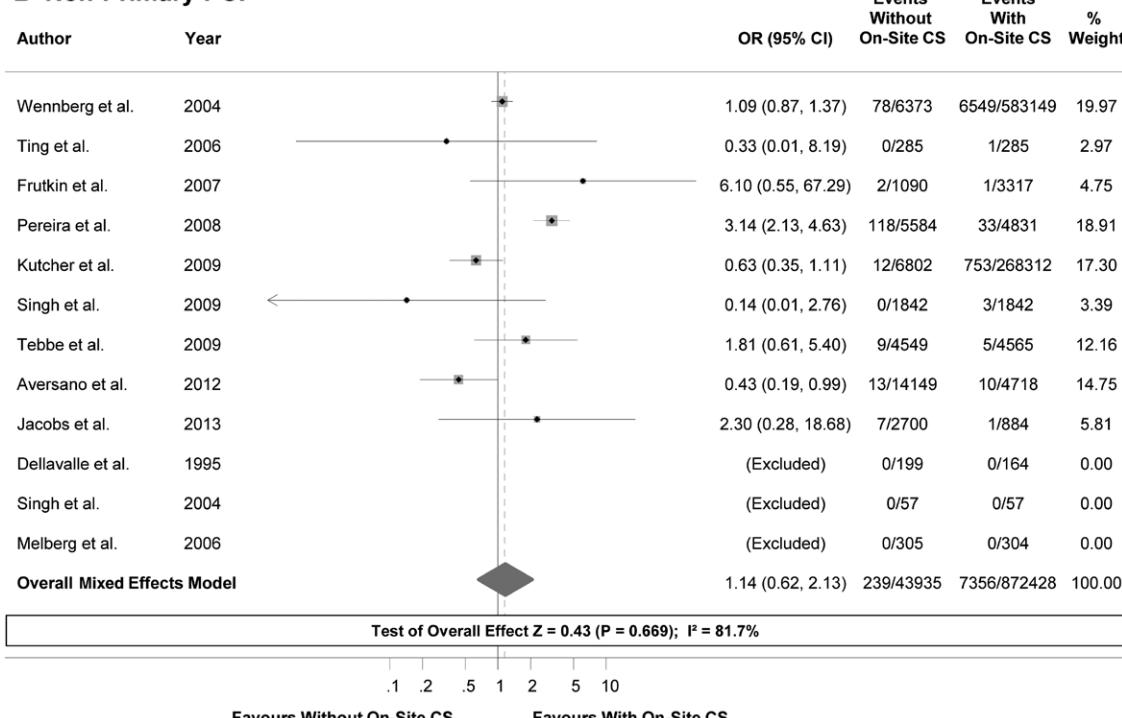
A Primary PCI**B Non-Primary PCI**

Figure 3. Forest plots comparing emergency surgery rates following PCI at centers with or without on-site surgery. ORs with 95% CIs are displayed for individual studies and the pooled overall effect. **A**, Primary PCI. **B**, Nonprimary PCI. CI indicates confidence interval; OR, odds ratio; and PCI, percutaneous coronary intervention.

133 574 (12.1%) patients underwent primary PCI because of STEMI. Of these primary PCIs, 20 793 (15.6%) were performed at centers without on-site surgery, and 112 781 (84.4%) were performed at centers with on-site surgery. In addition, 967 549 (87.9%) patients underwent nonprimary PCI for conditions other

than STEMI. Of these nonprimary PCIs, 58 670 (6.1%) and 908 879 (93.9%) were performed at centers without and with on-site surgery, respectively. All included studies reported all-cause mortality rate and 21 studies reported the emergency surgery rate. Interobserver agreement for study selection was high ($\kappa=0.94$).

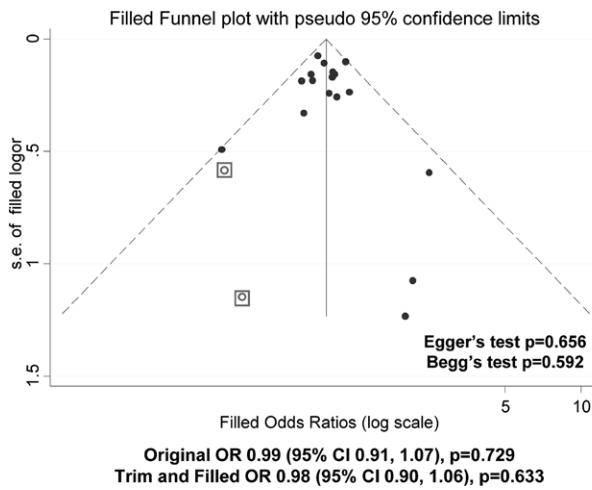
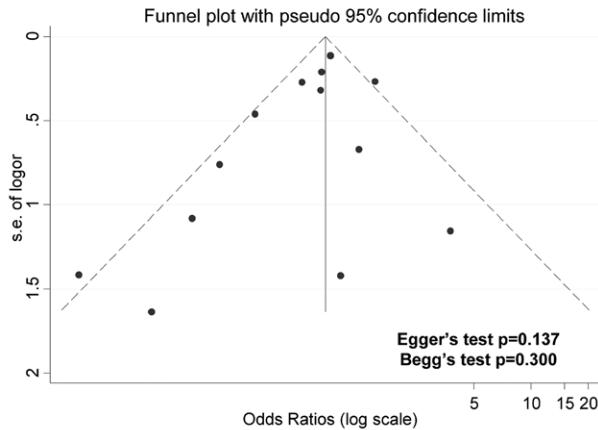
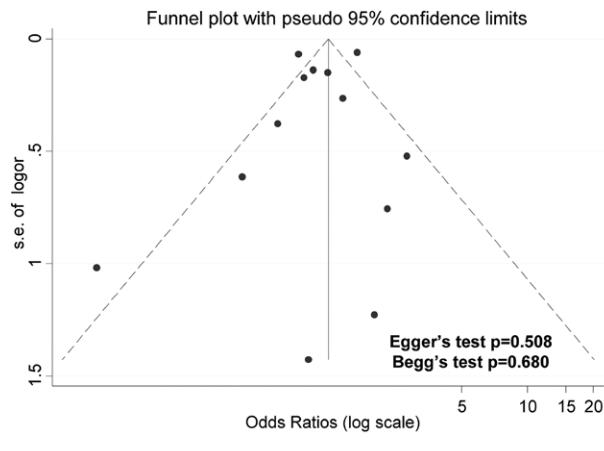
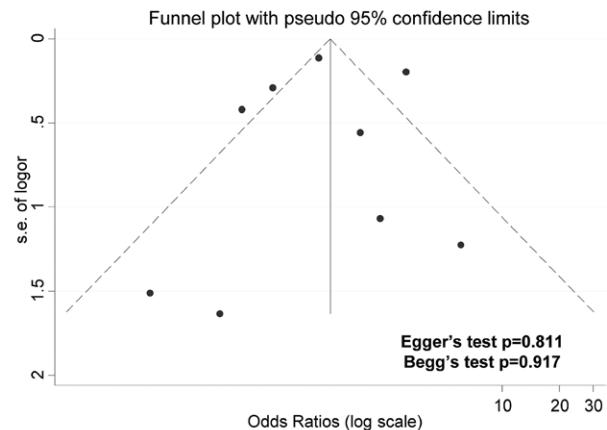
A All-cause Mortality in Primary PCI**C Emergency Surgery in Primary PCI****B All-cause Mortality in Non-Primary PCI****D Emergency Surgery in Non-Primary PCI**

Figure 4. Funnel plots for evaluation of publication bias. The results of the Egger and Begg tests are presented. When appropriate, the estimated odds ratio, trim-and-fill method, and the original odds ratio are shown. CI indicates confidence interval; OR, odds ratio; and PCI, percutaneous coronary intervention.

Study Characteristics and Risk of Bias Within Studies

The main characteristics of the 23 individual studies are summarized in the Table. Nineteen studies were prospective observational cohort or matched case-control studies^{7,10-14,17-29} and 4 were RCTs.^{2,3,15,16} All the nonrandomized studies reported adjusted rates of clinical outcomes by using propensity score-based adjustment, matching, or covariate adjustment. Eight studies exclusively enrolled STEMI patients who underwent primary PCI.^{11,12,15,19,20,23,25,29} Conversely, 6 studies exclusively evaluated patients after nonprimary PCI (elective or urgent PCI) for indications other than STEMI^{2,3,10,16,21,26}; 9 studies evaluated both primary and nonprimary PCI patients.^{13,14,17,18,22,24,27,28} All 9 studies reported group size and clinical outcomes according to PCI type. The proportion with 3-vessel disease was relatively higher in 7 studies than in other studies,^{7,13,15,17,21,22,27} ranging from 33.6% to 61.5% across these studies. The proportion with left main vessel PCI was reported by only 8 studies and was very low, ranging from 0.4% to 3.8% across these studies.

Tables II and III in the online-only Data Supplement summarize the bias risk assessment by study design. All the RCTs had no substantial risk of bias in random sequence generation and relatively high methodological quality. Although no RCT was double blinded, all trials defined clinical end points objectively. Therefore, the outcomes were unlikely to be influenced by the lack of blinding. All the nonrandomized studies met at least 17 variables of the strengthening the reporting of observational studies in epidemiology checklist; Table III in the online-only Data Supplement presents results of the Newcastle-Ottawa Scale.

Mortality and Emergency Surgery After Primary PCI
For 133 574 patients who underwent primary PCI for STEMI, the observed rates of all-cause mortality in pooled analysis were 7.2% and 4.8%, respectively, for centers with and without on-site surgery and did not differ based on pooled analysis using a mixed-effects model (pooled OR, 0.99; 95% CI, 0.91–1.07; $P=0.729$; Figure 2A). A fixed-effects model yielded similar results (pooled OR, 0.99; 95% CI, 0.91–1.07; $P=0.715$). Statistical heterogeneity was not revealed by either model ($I^2=3.4\%$).

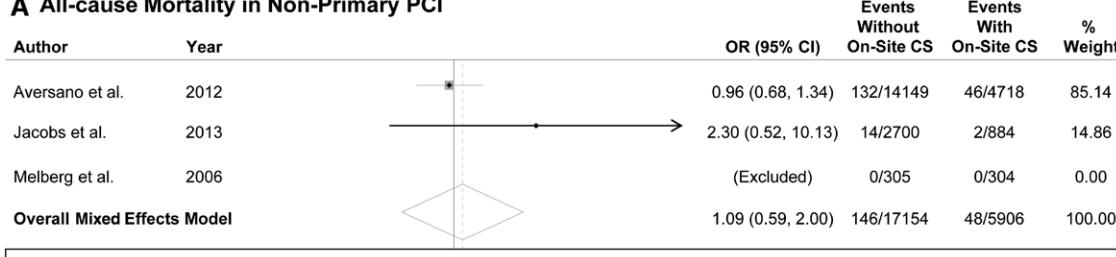
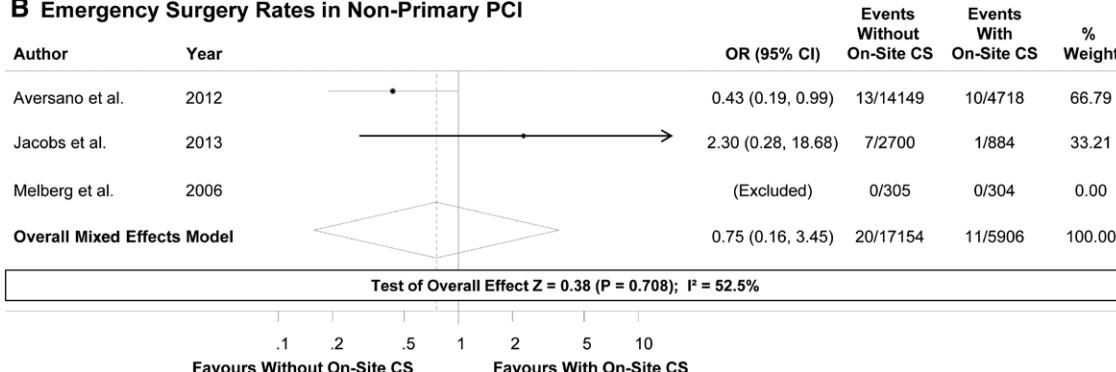
A All-cause Mortality in Non-Primary PCI**B Emergency Surgery Rates in Non-Primary PCI**

Figure 5. Forest plots, of only randomized, controlled trials, comparing all-cause mortality after PCI at centers with or without on-site surgery. ORs with 95% CIs are displayed for individual studies and the overall effect base on restricted pooled analysis of only randomized, controlled trials. CI indicates confidence interval; CS, cardiac surgery; OR, odds ratio; and PCI, percutaneous coronary intervention.

Observed rates of emergency surgery in pooled analysis were 2.4% and 1.5%, respectively, for centers with and without on-site surgery. Pooled analysis showed no differences in these rates, but moderate heterogeneity (pooled OR, 0.76; 95% CI, 0.56–1.01; $P=0.062$; $I^2=42.5\%$; Figure 3A).

Funnel plots, supported by the Egger and Begg tests, indicated no publication bias for all-cause mortality and emergency surgery outcomes (Figure 4A and 4C). The adjusted ORs, trim-and-fill method, for all-cause mortality showed similar results (pooled OR, 0.98; 95% CI, 0.90–1.06; $P=0.633$; Figure 4A). No individual study substantially influenced the pooled effect estimate for all-cause mortality (Figure 1A in the online-only Data Supplement). Exclusion of the Singh et al²⁷ or the Legutko et al²⁹ study influenced the pooled-effect estimates for emergency surgery; however, the overall trend of no difference in the risk of emergency surgery between centers with and without on-site surgery was not markedly changed (Figure 1B in the online-only Data Supplement).

Because follow-up periods differed, separate pooled analyses were performed for early (within 30 days) and late (after 30 days) all-cause mortality. For primary PCI, neither early mortality (pooled OR, 0.99; 95% CI, 0.91–1.08; $P=0.900$; $I^2=5.4\%$) nor late mortality (pooled OR, 1.08; 95% CI, 0.92–1.28; $P=0.338$; $I^2=0.0\%$) differed by the presence of on-site surgery (Figures IIIA and IVA in the online-only Data Supplement).

Mortality and Emergency Surgery After Nonprimary PCI

For 967549 patients who underwent nonprimary PCI for conditions other than STEMI, the observed rates of all-cause

mortality in pooled analysis were 2.1% and 1.6%, respectively, for centers with and without on-site surgery, and did not differ based on pooled analysis using a mixed-effects model (pooled OR, 1.15; 95% CI, 0.94–1.41; $P=0.172$; $I^2=67.5\%$; Figure 2B). Because of the considerable heterogeneity across the studies, pooled analysis with a fixed-effects model was considered inappropriate.

For such patients, observed rates of emergency surgery in pooled analysis were relatively low (0.8%, and 0.5% respectively, for centers with and without on-site surgery) and did not differ according to pooled analysis (pooled OR, 1.14; 95% CI, 0.62–2.13; $P=0.669$; $I^2=81.7\%$; Figure 3B). Symmetrical funnel plots of all-cause mortality and emergency surgery, with the support of the Egger and Begg tests, indicated no apparent publication bias (Figure 4B and 4D). The pooled-effect estimates for all-cause mortality or emergency surgery were not substantially influenced by any individual study (Figures 1B and IIIB in the online-only Data Supplement).

For patients who underwent nonprimary PCI, pooled analysis revealed considerable heterogeneity; therefore, restricted pooled analyses were also performed including only RCTs.^{2,3,16} Similar to the previous results, all-cause mortality (pooled OR, 1.09; 95% CI, 0.59–2.00; $P=0.796$; $I^2=21.6\%$) and emergency surgery rates (pooled OR, 0.75; 95% CI, 0.16–3.45; $P=0.708$; $I^2=52.5\%$) did not differ by the presence of on-site surgery (Figure 5).

Neither early mortality (pooled OR, 1.06; 95% CI, 0.74–1.52; $P=0.740$; $I^2=81.8\%$) nor late mortality (pooled OR, 0.85; 95% CI, 0.66–1.11; $P=0.232$; $I^2=73.4\%$) differed between centers with or without on-site surgery (Figures IIIB and IVB in the online-only Data Supplement).

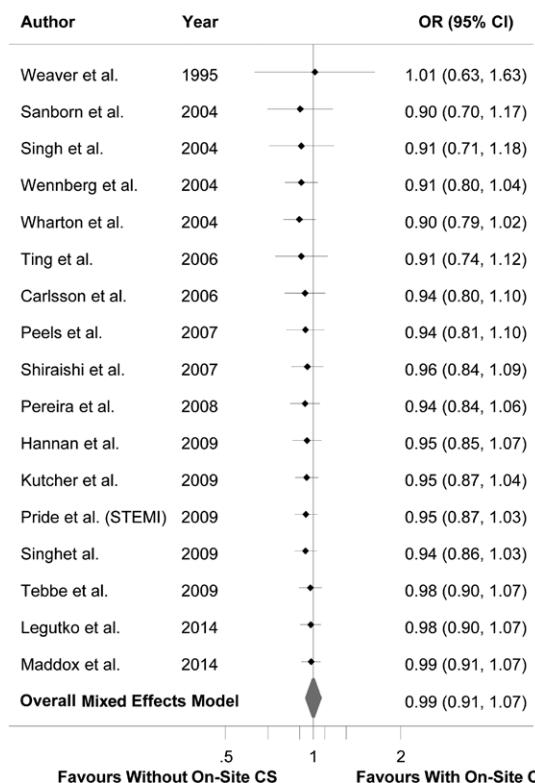
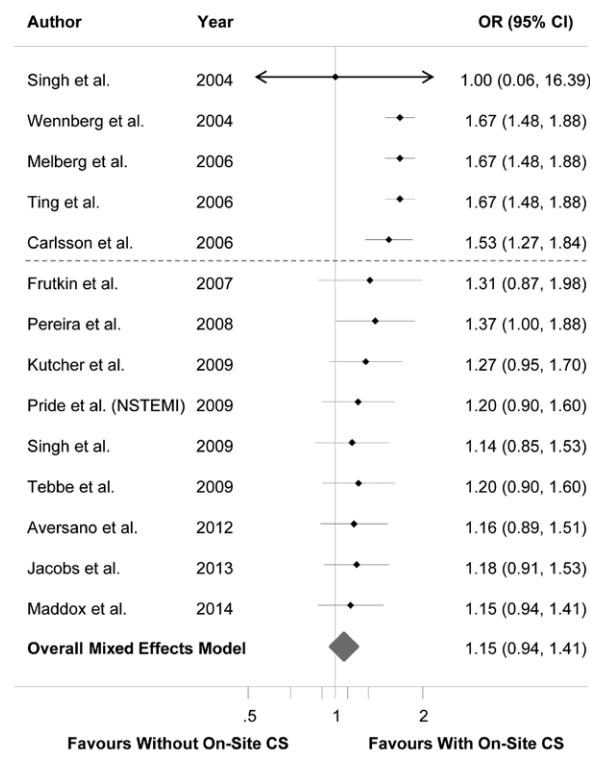
A Primary PCI**B Non-Primary PCI**

Figure 6. Cumulative meta-analysis of all-cause mortality according to the indication for percutaneous coronary intervention. **A**, Primary PCI. **B**, nonprimary PCI. The first row shows the effect of the earliest study, the second row shows the cumulative pooled effect estimate (OR) based on first 2 studies, and so on. CI indicates confidence interval; CS, cardiac surgery; NSTEMI, non-ST-segment-elevation myocardial infarction; OR, odds ratio; PCI, percutaneous coronary intervention; and STEMI, ST-segment-elevation myocardial infarction.

Temporal Trends of Mortality Rates After PCI

The results of cumulative meta-analysis, which sorts trials chronologically, revealed that temporal trends of the effect size

(OR) for all-cause mortality differed by indication for PCI. The pooled-effect size for all-cause mortality after primary PCI did not shift over time, despite the differences in practice patterns or

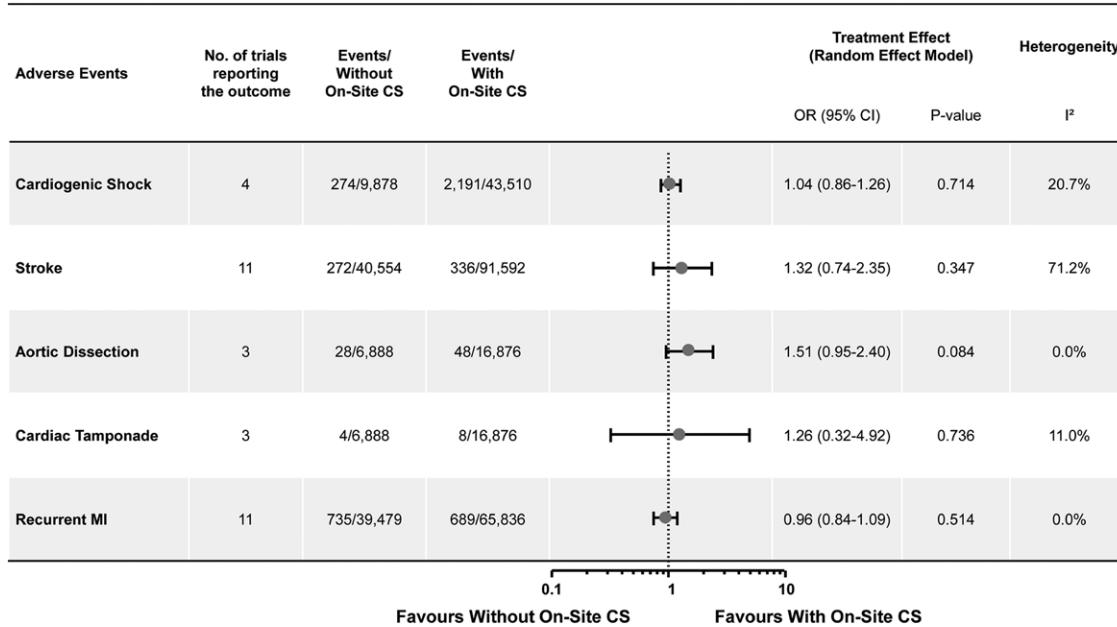


Figure 7. Forest plot comparing serious complications of percutaneous coronary intervention at centers with or without on-site surgery. The circles and horizontal lines indicate the odds ratios (by mixed-effects model) and the 95% confidence intervals for each complication. CI indicates confidence interval; CS, cardiac surgery; MI, myocardial infarction; OR, odds ratio; and PCI, percutaneous coronary intervention.

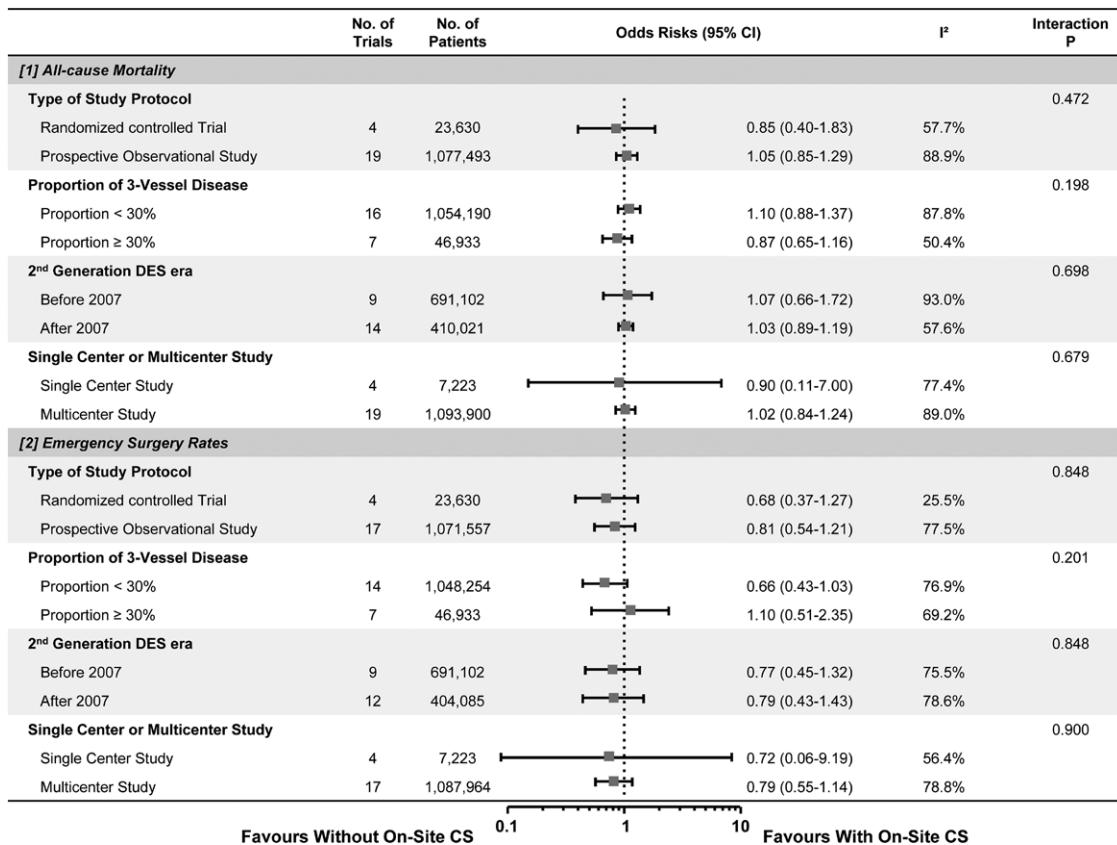


Figure 8. Forest plots depicting the results of subgroup analyses. Results are presented for analyses of these subgroups: (1) study design (RCT or prospective observational study); (2) proportion with 3-vessel disease (proportion <30% or ≥30%); (3) second-generation DES era (before 2007 or after 2007); and (4) whether the study is multicenter or single center. CI indicates confidence interval; CS, cardiac surgery; DES, drug-eluting stent; OR, odds ratio; PCI, percutaneous coronary intervention; and RCT, randomized, controlled trial.

patient populations from 1995 to 2014 (Figure 6A). In contrast, after 2007 to 2008, the pooled-effects size of all-cause mortality after nonprimary PCI shifted progressively, from greater toward equivalent risk, at centers without on-site surgery (Figure 6B).

Complications of PCI

The overall frequencies of serious complications of PCI were very low (stroke, 0.5%; aortic dissection, 0.3%; cardiac tamponade, 0.1%; and recurrent myocardial infarction, 1.4%), with the exception of cardiogenic shock (4.6%; Figure 7). These frequencies did not differ between centers with and without on-site surgery.

Subgroup Analyses

The results of subgroup analyses of the outcome all-cause mortality resembled those of the overall analyses and showed no differences between centers with and without on-site surgery (Figure 8). No significant interaction was observed across the various subgroups.

Discussion

We performed an updated systemic review and meta-analysis that compared clinical outcomes and complications after PCI between centers with or without on-site surgical backup. The principal findings were as follows. (1) After primary PCI for

STEMI, centers without on-site surgery did not differ from centers with on-site surgery in the rates of all-cause mortality, emergency surgery, and serious complications of PCI. In addition, effect size did not change over time despite substantial temporal changes in practice patterns, revascularization methods, and adjunctive pharmacotherapy for STEMI. Heterogeneity across the studies was minimal and publication bias was not suspected. (2) Similarly, after nonprimary PCI for conditions other than STEMI, the rates of all-cause mortality, emergency surgery, and serious complications of PCI did not differ in centers with and without on-site surgery. Publication bias was not suspected, and these findings were consistent across various subgroups. Although the overall pooled analysis had considerable heterogeneity for all-cause mortality and emergency surgery, a restricted pooled analysis of only RCTs showed similar findings with much lowered heterogeneity. (3) Interestingly, after 2007 to 2008, there was a clear trend in the effect size (OR), from greater toward equivalent risk, for all-cause mortality following nonprimary PCI in centers without on-site surgery. (4) Regardless of the presence of on-site surgery, the overall frequencies of emergency surgery and serious complications of PCI were very low, especially after nonprimary PCI. The equivalence of centers with and without on-site surgery in clinical outcomes and complication rates after nonprimary

PCI suggests widespread standardization of PCI technique, devices, and clinical practice patterns. Furthermore, the equivalent outcomes after primary PCI supports the current strategy of increasing access to cardiac catheterization laboratories and consequent reperfusion.

Reappraisal of the Rationale for On-Site Surgery

During the initial years of coronary balloon angioplasty, ≈6.6% of patients required emergency surgery because of procedure-related complications.⁴ Thereafter, improvements in techniques and devices, wide use of more advanced DES, and increasing operator experience were followed by decreasing rates of emergency surgery to 0.14% to 0.37%.^{4,24} In addition, because primary PCI has been proven to produce significantly better outcomes than thrombolysis, improved access to primary PCI has become more important. Moreover, increasing evidence supports noninferior clinical outcomes of PCI at centers without on-site surgery, in comparison with centers with on-site surgery.^{12,15,19,23} These aforementioned factors have contributed to the expansion of PCIs performed in centers without on-site surgery.

Primary PCI Without On-Site Surgery

Previous meta-analyses^{6,30} and the current meta-analysis consistently showed that the safety (in-hospital mortality and need for emergency surgery) and efficacy (procedural success and longer-term survival) of primary PCI performed without on-site surgery was similar to that performed with on-site surgery. The current meta-analysis found equivalent clinical outcomes, and serious complications of PCI, as well, that were not evaluated in previous analyses. It should be noted that the rates of emergency surgery were ≈0.9% higher in centers with on-site surgery despite the lack of statistical significance. The tendency of higher emergency surgery rates in centers with on-site surgical backup could reflect lower thresholds for emergency surgery in these centers. This explanation is supported by the similar frequencies of serious PCI complications, the main indications for emergency surgery.

Considering these results, rather than mandating on-site surgical backup for possible emergent conditions, the following potential strategies to improve patient outcomes should be encouraged: maintaining the quality of care in individual PCI centers (such as a global quality assurance program); reducing total ischemic time (both door-to-balloon time and pain-to-hospital time); improving community recognition of and response to cardiac events; and optimizing posttreatment follow-up, including secondary prevention and cardiac rehabilitation.^{4,31}

Nonprimary or Elective PCI Without On-Site Surgery

For nonprimary PCI, the debate regarding the need for on-site surgical backup is more complex than for primary PCI; neither the necessity for rapid access nor anticipated survival benefits require performing nonprimary PCI at centers without on-site surgery.⁴ The expansion of nonprimary PCI to centers without on-site surgery has advantages and disadvantages. The advantages may include greater hospital choice,

greater opportunity to remain close to home, more continuity of care with local physicians, closer postoperative follow-up, and enhanced secondary prevention. However, these advantages should be balanced with potential disadvantages, such as the incremental risks of life-threatening complications and resultant mortality.^{2,4,32}

Data about clinical outcomes in centers without on-site surgery have been conflicting. Analysis of Medicare administrative data by Wennberg et al¹⁴ generated concern about the safety of PCI without on-site surgical backup. They reported significantly higher mortality rates in hospitals without on-site surgery than in those with on-site surgery (4.6% versus 2.8%; adjusted OR, 1.38; 95% CI, 1.14–1.67) among the 589 522 patients who underwent nonprimary or rescue PCI. However, caution is warranted in interpreting these results. Because the study periods ranged from 1999 to 2001, the results may not reflect contemporary practices for nonprimary PCI, such as more advanced and improved technologies, including DES and pharmacotherapy that improve the safety of PCI. Moreover, 25% of the centers without on-site surgery performed ≤25 PCIs annually.^{14,32}

A previous meta-analysis by Singh et al⁶ evaluated the safety of nonprimary PCI without on-site surgery among 914 288 patients from 9 nonrandomized observational studies. Although the pooled analysis of in-hospital death rates did not differ significantly between centers with and without on-site surgery (OR, 1.15; 95% CI, 0.93–1.41), the mortality rates after adjustment of publication bias (with trim-and-fill method) were significantly higher in centers without on-site surgery (corrected OR, 1.25; 95% CI, 1.01–1.53; $P=0.04$). However, among the total 15 studies included in this meta-analysis, all were nonrandomized observational studies except for 1 RCT. In addition, the discrepancy between the original pooled analysis and trim-and-filled adjusted analysis hinders definite conclusions regarding the nonprimary PCIs performed in centers without on-site surgery.

In contrast to previous studies, the recently published large-scale RCTs (CPORT-E and MASS COMM trial) found no significant differences in all-cause mortality and emergency surgery rates after nonprimary PCI.^{2,3} The CPORT-E trial randomly assigned 14 149 patients to PCI at centers without on-site surgery and 4718 patients to PCI at centers with on-site surgery. The 6-week mortality rates (0.9% versus 1.0%; 95% CI of difference, −0.31 to 0.23; $P=0.004$ for noninferiority) and 9-month rates of major adverse cardiac events (all-cause mortality, Q-wave myocardial infarction, target vessel revascularization; 12.1% versus 11.2%; 95% CI of difference, 0.04–1.80; $P=0.05$ for noninferiority) did not differ between centers with and without on-site surgery.

The MASS COMM trial confirmed noninferiority of non-emergency PCI performed at centers without on-site surgery to centers with on-site surgery among 3691 patients. The rates of major adverse cardiac events were 9.5% and 9.4% at 30 days (relative risk, 1.00; 95% 1-sided limit, 1.22; noninferiority margin, 1.5; $P<0.001$ for noninferiority), and 17.3% and 17.8%, respectively, at 12 months (relative risk, 0.98; 95%

1-sided limit, 1.13; noninferiority margin, 1.3; $P<0.001$ for noninferiority).

The CPORT-E and MASS COMM trials had similar findings regarding mortality and major adverse cardiac events; however, in general, the CPORT-E population had higher risk profiles than the MASS COMM population. For example, the CPORT-E population had a relatively higher frequency of left main disease (CPORT-E versus MASS COMM: 3.4% versus 0.7%), multivessel PCI (20.9% versus 15.4%), and previous history of PCI (31.5% versus 28.5%) and coronary artery bypass grafting (13.2% versus 5.8%). Nonetheless, the safety and efficacy of PCI did not differ by presence of on-site surgery.

With the inclusion of these 2 large-scaled pivotal trials in the pooled analysis, our meta-analysis confirmed similar risks of all-cause mortality and emergency surgery after nonprimary PCI in centers without on-site surgery without evidence of publication bias. Moreover, the results were consistent across various subgroups, including $\geq 30\%$ of patients with 3-vessel disease. The safety of nonprimary PCI without on-site surgical backup was also supported by very low rates of serious complications of PCI in centers without on-site surgery. To our knowledge, this is the most comprehensive meta-analysis; it includes the largest number of high-quality studies.

Of note, after 2007 to 2008, we observed a temporal trend in the effect size (OR), from greater toward equivalent risk, for all-cause mortality after nonprimary PCI in centers without on-site surgery. Possible reasons for this temporal trend are as follows. First, despite the 2007 American College of Cardiology Foundation/American Heart Association/Society for Cardiovascular Angiography and Interventions guideline containing a class III recommendation for nonprimary PCI without on-site surgical backup, many studies continue to report nonsignificant differences of outcomes, including reports about nonprimary PCI during 2006 to 2007,¹⁶⁻¹⁸ and the number of PCIs performed without onsite surgery has increased since 2007 across the United States.¹ Second, the expanded use of DES since 2006 to 2007, especially second-generation DES with improved flexibility, deliverability, technical success rates, and safety profile (ie, significantly reduced fatal stent thrombosis rates), might explain this trend.³³ Nonetheless, this finding should be regarded as hypothesis generating.

It should be also noted that we could not evaluate target vessel revascularization (TVR), an important index of PCI efficacy, owing to the paucity and inconsistent reporting of TVR data. In the CPORT-E trial, the 9-month TVR rates after nonprimary PCI in centers without on-site surgery were significantly higher than in centers without on-site surgery, regardless of the TVR definition or stent types (6.5% versus 5.4%; $P=0.01$). However, the more recently published MASS COMM trial reported numerically lower, but not significantly different, rates of TVR in centers without on-site surgery at 12 months (8.5% versus 9.9%; relative risk, 0.86; 95% CI, 0.67–1.11; $P=0.24$). Pooled analysis of these 2 RCTs found no difference in TVR rates (OR, 1.04; 95% CI, 0.75–1.45; $P=0.810$; $P=78.6\%$). The rationale for allowing nonprimary PCI to be performed in centers without on-site

surgery is to enhance patient convenience and maintain continuity of medical care; hence, further study is warranted to evaluate the impact of nonprimary PCI without on-site surgery on repeat revascularization, subsequent medical costs, and quality of life.

Limitations

Some important limitations of the current study should be considered. First, this meta-analysis included clinically and methodologically diverse studies. Although no evidence of publication or small study bias was noticed, the pooled analysis of nonprimary PCI found considerable heterogeneity. However, heterogeneity was primarily attributable to differences in the patient population and the variance of each summary measure. Studies that were conducted in the earlier period, that is, without access to improved technologies such as DES, might be the source of heterogeneity. Restricted, pooled analysis of nonprimary PCIs that included only RCTs showed much lowered heterogeneity and results similar to the full analysis. Second, because this is a study-level meta-analysis, we could not adjust for patient-level confounders and unmeasured confounders, such as operator experience; technical ability; type of medical center (private or public institution); adequacy of medical treatment, including secondary prevention; and, importantly, annual volume of PCIs performed in each institution. Third, most of the included studies categorized urgent PCI for non-STEMI as nonprimary PCI, therefore, our results might not represent clinical outcomes of elective PCI for stable angina or silent ischemia. Last, information regarding the specific measures of revascularization, for example, balloon angioplasty, bare-metal stent, and first- or second-generation DES, were reported inconsistently and partially in each of the included studies. Therefore, we could not perform analyses stratified by the method of revascularization.

Conclusions

The clinical outcomes and complication rates of patients treated with PCI at centers without on-site surgery did not differ from centers with on-site surgery, for both primary and nonprimary PCI. Temporal trends of improving clinical outcomes for nonprimary PCI at centers without on-site surgery were observed. Further studies are warranted, including the comparison of rates of repeat revascularization, medical costs, and quality of life, especially after nonprimary PCI.

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Disclosures

None.

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CLINICAL PERSPECTIVE

In the current era of stents, the rate of serious complications and subsequent need of emergency surgery has dramatically decreased, with an incidence of 0.1% to 0.4%. Despite this progress, the concern for performing percutaneous coronary intervention (PCI) at centers without on-site surgical backup has persisted, especially in nonprimary PCI for conditions other than ST-segment-elevation myocardial infarction. Whether PCI at centers without on-site surgical backup will increase the risk of adverse outcomes and complications remains elusive, especially for nonprimary PCI. In this updated meta-analysis with 1 101 123 patients from 23 high-quality studies, the rates of all-cause mortality, emergency coronary artery bypass graft surgery, and other complications were not different between centers with and without on-site surgery, regardless of primary or nonprimary PCI. Cumulative meta-analysis for nonprimary PCI showed temporal decrease of the difference in all-cause mortality since 2007, suggesting temporal trends of improving outcomes in nonprimary PCI at centers without on-site surgery. These results suggest the safety of PCI at centers without on-site surgical backup, for both primary and nonprimary PCI. However, because the rationale for allowing nonprimary PCI to be performed in centers without on-site surgery is to enhance patient convenience and maintain the continuity of medical care, further study is warranted to evaluate the impact of nonprimary PCI without on-site surgery on repeat revascularization, subsequent medical costs, and quality of life.

Supplementary Material

Clinical Outcomes of Percutaneous Coronary Intervention at Centers With or Without On-Site Surgical Back-Up: Updated Study-Level Meta-analysis of 23 Studies

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Supplementary Methods

Data Sources and Searches

Study Selection

Data Extraction and Quality Assessment

Outcomes and Definitions

Data Synthesis and Analysis

Search Strategy on Medline, EMBASE and Cochran Central

Characteristics of the Excluded Study

Supplementary Tables

Supplementary Table 1. Checklist of items to include when reporting a systematic review or meta-analysis (PRISMA guidelines)

Supplementary Table 2. The Cochrane Collaboration's tool for assessing risk of bias of 4 randomised clinical trials in meta-analysis

Supplementary Table 3. The Newcastle-Ottawa Scale for assessing the quality of 19 nonrandomised studies in meta-analysis

Supplementary Figure Legends

Supplementary Figure 1. Influence of Individual Studies for All-cause Mortality, According to the Indication of Percutaneous Coronary Intervention

Supplementary Figure 2. Influence of Individual Studies for Emergency Surgery Rates, According to the Indication of Percutaneous Coronary Intervention

Supplementary Figure 3. Comparison of Early Mortality Following Percutaneous Coronary Intervention at Centers With or Without On-site Surgery

Supplementary Figure 4. Comparison of Late Mortality Following Percutaneous Coronary Intervention at Centers With or Without On-site Surgery

References

Supplementary Methods

Data Sources and Searches

Pertinent published or unpublished studies were independently searched in PubMed, EMBASE, Cochrane Central Register of Controlled Trials, and the United States National Institutes of Health registry of clinical trials (www.clinicaltrials.gov), and the relevant websites (www.crtonline.org, www.clinicaltrialresults.com, www.tctmd.com, www.cardiosource.com, and www.pcronline.com) were also searched. Detailed search strategy is presented in the Supplementary Appendix. Additional data sources include conference proceedings from the American College of Cardiology, the European Society of Cardiology, the American Heart Association, Transcatheter Cardiovascular Therapeutics, and the World Congress of Cardiology. The electronic search strategy was complemented by manual review of the reference list of included articles. References of recent reviews, editorials, and meta-analyses were also examined. No restrictions were imposed on language, study period, or sample size.

Study Selection

Studies that met each of following criteria were considered eligible for meta-analysis. First, the results including complications and clinical outcomes, including all-cause mortality or need of emergency surgery, from a center without on-site surgical back-up were clearly reported. Second, the outcomes of PCI were compared with a center with on-site surgical back-up Third, for studies focused on primary PCI, a clear definition of STEMI was reported. Last, RCT or non-randomized prospective observational studies were considered eligible. For non-

randomized prospective observational studies, statistical adjustment of baseline difference between centers with or without on-site surgical back-up was appropriately used (for example, propensity score-based adjustment, matching, covariate adjustment). We did not include studies which reported PCI outcomes without a comparison or control group. Two investigators (J.M.L and D.H) independently performed screening of titles and abstracts, identified duplicates, reviewed full articles, and determined their eligibility. Disagreements were resolved by discussion. The last search was performed in January 2015.

Data Extraction and Quality Assessment

Summary data as reported in the published manuscripts were used in the analysis. A standardized form was used to extract characteristics of studies, study design (including randomization sequence generation, allocation concealment, crossover between assigned groups, number of post-randomization withdrawals or loss to follow-up for the RCT; inclusion and exclusion criteria, comparability of study cohort and control group, independent blind outcome assessment, length of follow-up, completeness of follow-up for non-randomized prospective observational study), number of study patients, type of PCI (primary PCI or non-primary PCI), age, clinical and angiographic eligibility criteria including clinical diagnosis, definition of STEMI, proportion of 3-vessel disease or left main vessel intervention, proportion of cardiovascular risk factors (male, hypertension, diabetes mellitus, chronic kidney disease, dyslipidemia, previous stroke, previous CABG, previous history of MI). The rates of all-cause mortality, in-hospital mortality, early mortality (within 30-day), late mortality (after 30-day), need for emergency surgery, complications related to PCI (stroke, cardiogenic shock, coronary dissection, cardiac tamponade, recurrent MI)

were collected with its definition reported on an intention-to-treat basis. Patients with STEMI did not include those with facilitated PCI or rescue PCI, and these patients were likely to be included as NSTEMI patients in the non-primary PCI group. In studies which enrolled both primary and non-primary PCI patients, sample size and number of events were separately extracted, according to the primary or non-primary PCI group. Our analysis was focused primarily on comparison of all-cause mortality, need for emergency surgery, and PCI complications between centers without on-site surgery and with on-site surgery.

The quality of eligible studies was assessed using the Cochrane Collaboration's tool for assessing the risk of bias for RCTs, the Newcastle-Ottawa Scale (NOS) and the strengthening the reporting of observational studies in epidemiology (STROBE) checklist for non-randomized prospective observational studies. We did not exclude individual studies based on the specific threshold of NOS or STROBE checklist for the analysis.

Outcomes and Definitions

The primary outcome was the rates of all-cause mortality at the longest available follow-up. Secondary outcomes included the need for emergency surgery related to the use of PCI, all-cause mortality stratified by reported time (early mortality was defined as occurring within 30-days of the index procedure and late mortality was defined as occurring after 30-days of the index procedure), and complications of PCI (stroke, cardiogenic shock, coronary dissection, cardiac tamponade, recurrent MI). If data were duplicated between studies, the most recent study was used. All patients and outcomes were separately analyzed according to type of PCI (primary PCI or non-primary PCI), and

analyzed according to the originally assigned group.

Data Synthesis and Analysis

Primary and secondary outcomes were analyzed by mixed-effects model. Odds ratio (OR) with 95% confidence intervals (CI) were presented as summary statistics. Since all included studies showed heterogeneity regarding study protocol and populations, the fixed-effects model was only used as sensitivity analyses to check whether these models yielded similar results. The pooled OR and 95% confidence intervals were calculated with the restricted maximum likelihood (REML) method for mixed-effects as well as the Mantel–Haenszel method for fixed-effects.¹ Because of progressive changes in primary study designs and clinical practice patterns, especially revascularization method (balloon angioplasty, bare metal stent, 1st or 2nd generation DES), we evaluated the impact of publication date on the overall effect of pooled ORs for rates of all-cause mortality by a cumulative meta-analysis. In cumulative meta-analysis, the pooled estimate of the treatment effect is updated each time the results of a new study are added.² Therefore cumulative meta-analysis is the repeated performance of a meta-analysis whenever new studies become available for inclusion. Since all of the included studies in the cumulative meta-analysis had the same comparison groups, cumulative pooled estimates up to time point of last study inclusion could reflect possible temporal trends in outcome measures.

All study outcomes were separately analyzed according to primary or non-primary PCI. Statistical heterogeneity was quantified with the I² statistics. Publication bias was assessed by funnel plot asymmetry, along with Egger's and Begg's test and when any visual asymmetry

of funnel plot was suspected, the trim-and-fill method was used to estimate the number of missing studies and to calculate a corrected OR, as if these studies were present.³ The influence of an individual study was explored with estimating pooled OR, with stepwise exclusion of 1 study.

Subgroup analyses were performed to see whether the results were different across subgroups. Subgroup analyses were done for: (1) study protocols (RCT or prospective observational study) ; (2) proportion of 3-vessel disease (proportion < 30% or \geq 30%) ; (3) 2nd generation DES era (before 2007 or after 2007) ; and (4) whether the study is multi-center or single center. Results were considered statistically significant at 2-sided p<0.05. Statistical analysis was performed with using STATA/SE 12.0 (Stata Corp LP, College Station, Texas, USA) and R programming language, version 3.1.1 (R Foundation for Statistical Computing). The present study was performed in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Supplementary Table 3) as well as the Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines. The review protocol has not been registered.

Search Strategy

Pubmed			EMBASE			Cochrane Library		
#14	#4 and #13	667	#14	#4 and #13	1091	#14	#4 and #13	507
#13	#5 or #6 or #7 or #8 or #9 or #10 or #11 or #12	40327	#13	#5 or #6 or #7 or #8 or #9 or #10 or #11 or #12	43299	#13	#5 or #6 or #7 or #8 or #9 or #10 or #11 or #12	7911
#12	'Cardiac surgery'	28116	#12	'Cardiac surgery'	30572	#12	'Cardiac surgery'	7292
#11	'off-site'	1114	#11	'off-site'	1135	#11	'off-site'	81
#10	'Offsite'	259	#10	'Offsite'	283	#10	'Offsite'	9
#9	'on-site'	10113	#9	'on-site'	10036	#9	'on-site'	526
#8	'Onsite'	1236	#8	'Onsite'	1613	#8	'Onsite'	63
#7	'Surgical backup'	79	#7	'Surgical backup'	302	#7	'Surgical backup'	11
#6	'Surgery backup'	25	#6	'Surgery backup'	455	#6	'Surgery backup'	19
#5	'Surgical standby'	41	#5	'Surgical standby'	111	#5	'Surgical standby'	3
#4	#1 or #2 or #3	29929	#4	#1 or #2 or #3	52499	#4	#1 or #2 or #3	7532
#3	'Primary angioplasty'	1806	#3	'Primary angioplasty'	5172	#3	'Primary angioplasty'	2225
#2	'Percutaneous Coronary intervention'	17046	#2	'Percutaneous Coronary intervention'	31352	#2	'Percutaneous Coronary intervention'	4037
#1	'Coronary angioplasty'	12210	#1	'Coronary angioplasty'	21538	#1	'Coronary angioplasty'	8222

Characteristics of the Excluded Studies

No.	Title	First Author	Journal	Main Reason for Exclusion
1	Use of direct angioplasty for treatment of patients with acute myocardial infarction in hospitals with and without on-site cardiac surgery.	Weaver, W. D et al	Circulation 1993	Duplicate date
2	Low-risk percutaneous coronary interventions without on-site cardiac surgery: Two years' observational experience and follow-up.	Ting, H.H. et al.	American Heart Journal 2003	Duplicate date
3	Organization of care for acute myocardial infarction in rural and urban hospitals in Kansas.	Ellerbeck, E. F. et al.	Journal of Rural Health 2004	This article was not about surgical back up.
4	Comparison of primary angioplasty in rural and metropolitan areas within an integrated network.	Giuliani, G et.al.	EuroIntervention 2008	This article was not about surgical back up.
5	Primary percutaneous coronary intervention with or without cardiac surgery on-site: Massachusetts' experience.	Anis, A. et al.	Circulation 2010	Non available full data regarding mortality and emergency CABG rates
6	Percutaneous coronary intervention for acute coronary syndromes in centers with and without onsite cardiac surgery. analysis from PL-ACS registry.	Ganullsior, M. et al.	Journal of the American College of Cardiology 2010	Non available full data regarding mortality and emergency CABG rates

7	A comparison of the health status after percutaneous coronary intervention at a hospital with and without on-site cardiac surgical backup: A randomized trial in nonemergent patients.	Melberg, T. et al.	Cardiovascular Prevention and Rehabilitation 2010	This article's main point was about symptom control between surgical back up group and non-surgical back up group. Non available full data regarding mortality and emergency CABG rates
8	Outcomes of non-primary PCI at hospitals with and without on-site cardiac surgery: A randomized study. Circulation	Aversano, T. et al.	Circulation 2011	This article was description of study plan (trial design paper)
9	Clinical outcomes of primary percutaneous coronary interventions for acute myocardial infarctions in hospitals with and without onsite cardiac surgery backup.	Kim, M. K. et al.	American Journal of Cardiology 2011	Non available full data regarding mortality and emergency CABG rates
10	Rationale and design of the MASS COMM trial: A randomized trial to compare percutaneous coronary intervention between MASSachusetts hospitals with cardiac surgery on-site and COMMunity hospitals without cardiac surgery on-site.	Mauri, L. et al.	American Heart Journal 2011	This article was description of study plan (trial design paper)
11	Outcome of percutaneous coronary intervention in institutions with and without on-site cardiac surgery standby: Analysis of a monitor controlled registry (QUIK).	Reifart, N. et al.	European Heart Journal 2011	Non available full data regarding mortality and emergency CABG rates
12	Aversano, T. et al. 2012. Acute complications of non-primary PCI at hospitals with and without on-site cardiac surgery: CPRT-E project.	Aversano, T. et al.	Journal of the American College of Cardiology 2012	Duplicate data
13	Outcomes of non-primary percutaneous coronary intervention at hospitals with and without on-site cardiac surgery: A randomized study.	Aversano, T. et al.	European Heart Journal 2012	Duplicate data

14	Clinical outcomes of percutaneous coronary intervention (PCI) at hospital with or without onsite cardiac surgery backup in Japan.	Akasaka, T. et al.	Circulation 2013	Non available full data regarding mortality and emergency CABG rates
15	Characteristics of patients with coronary artery disease treated with multivessel percutaneous coronary intervention in hospitals with and without on-site cardiac surgery in Quebec: A province-wide field evaluation.	Lambert, L. J. et al.	Canadian Journal of Cardiology 2014	Non available full data regarding mortality and emergency CABG rates
16	Comparison of primary angioplasty results with and without cardiac surgery backup in a single center.	Mansuronulllu, C. et al.	American Journal of Cardiology 2014	Non available full data regarding mortality and emergency CABG rates

Supplementary Tables

Supplementary Table 1. Checklist of items to include when reporting a systematic review or meta-analysis (PRISMA guidelines)

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	3
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	6
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	9
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	6
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	6-7
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	6-7 and Supplementary Appendix
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	6-7 and Supplementary Appendix
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	7-8 and Supplementary Appendix
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	7-8 and Supplementary Appendix
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7-8 and Supplementary Appendix

Section/topic	#	Checklist item	Reported on page #
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	8-9 and Supplementary Appendix
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	8-9 and Supplementary Appendix
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	8-9 and Supplementary Appendix
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	8-9 and Supplementary Appendix
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	10 and Figure1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Table 1
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12).	Supplementary Table 2, Supplementary Table 3
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	Figure 2, 3
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	10-13 and Figure 2, 3
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	11, Supplementary Table 2-3
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	13-14 and Figure 5, 6, 7, 8 and Supplementary Figure 1-4
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., health care providers, users, and policy makers).	14-15
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review level (e.g., incomplete retrieval of identified research, reporting bias).	20-21
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	21

Section/topic	#	Checklist item	Reported on page #
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	22

Supplementary Table 2. The Cochrane Collaboration's tool for assessing risk of bias of 4 randomised clinical trials in meta-analysis

Study	Domain	Support for judgment & review authors' judgment
Wharton, T. P., Jr. et al.	Random Sequence Generation	Low risk of bias. Patients were randomly allocated although the specific manner of random sequence generation was not reported.
	Allocation concealment	Low risk of bias. Although maintaining allocation concealment of participants and medical personnel is inherently impossible since each randomized patients were transferred to other hospital for primary PCI or underwent on-site treatment, however, clinical outcomes were assessed by independent clinical events committee, which was blinded to the treatment received.
	Blinding of participants and personnel	Low risk of bias. The blinding of participants and medical personnel is inherently impossible since each randomized patients were transferred to other hospital for primary PCI or underwent on-site treatment. However, since all primary and secondary endpoints were objective findings (all-cause mortality or need of emergency surgery), therefore, judged that the outcome is not likely to be influenced by lack of blinding.
	Blinding of outcome assessment	Low risk of bias. All primary end points, as well as a random sampling of 20% of patients, were reviewed by the clinical events committee, which was blinded to the treatment received.
	Incomplete outcome data	Low risk of bias. Only 1 patient in on-site treatment group was missing from the analysis. Other patients in both groups were completely followed to the end of the study.
	Selective reporting	Low risk of bias. All of the study's pre-specified (primary and secondary) outcomes that are of interest in the review have been reported in the pre-specified manner.
	Other sources of bias	Low risk of bias. The study appears to be free of other sources of bias.
Melberg, T. et al.	Random Sequence Generation	Low risk of bias. Patients were randomized in blocks of 4 using sealed opaque envelopes.
	Allocation concealment	Low risk of bias. Maintaining allocation concealment of participants and medical personnel is inherently impossible since each randomized patients were transferred to other hospital or underwent on-site treatment. The review author judged that lack of allocation concealment is not likely to influence to the results of the current study.
	Blinding of participants and personnel	Low risk of bias. The blinding of participants and medical personnel is inherently impossible since each randomized patients were transferred to other hospital or underwent on-site treatment. However, since all primary and secondary endpoints were objective findings (all-cause mortality or need of emergency surgery), therefore, judged that the outcome is not likely to be influenced by lack of blinding.
	Blinding of outcome assessment	Low risk of bias. All clinical events during the follow-up period and clinical status for each patient were captured in the PCI database or from the hospitals' patient information systems. Although the independent adjudication of clinical events were not performed, all of the endpoints were objective findings (death, emegency surgery, myocardial infarction, tamponade, aortic dissection, pseudoaneurysm, CVA).
	Incomplete outcome data	Low risk of bias. Among the total 609 patients who were randomized to either PCI at regional

		hospital or PCI at community hospital, 5 patients who did not undergo PCI were excluded from the final analysis.
	Selective reporting	Low risk of bias. All of the study's pre-specified outcomes that are of interest in the review have been reported in the pre-specified manner.
	Other sources of bias	Low risk of bias. The study appears to be free of other sources of bias.
Aversano, T. et al.	Random Sequence Generation	Low risk of bias. Randomization was performed with the use of an automated telephoneresponse system on a per-site basis in random permuted blocks (of 4, 8, or 12).
	Allocation concealment	Low risk of bias. Although maintaining allocation concealment of participants and medical personnel is inherently impossible since each randomized patients were transferred to other hospital or underwent on-site treatment, however, clinical outcomes were assessed by independent clinical events committee, which was blinded to the treatment received.
	Blinding of participants and personnel	Low risk of bias. The blinding of participants and medical personnel is inherently impossible since each randomized patients were transferred to other hospital or underwent on-site treatment. However, since all primary and secondary endpoints were objective findings, therefore, judged that the outcome is not likely to be influenced by lack of blinding.
	Blinding of outcome assessment	Low risk of bias. All events were reported by the enrolling site to the central coordinating center and were confirmed by coordinating-center staff with the source medical records submitted. A central review committee reviewed electrocardiographic findings without knowledge of the participant's randomized assignment.
	Incomplete outcome data	Low risk of bias. All of the analyses were performed with intention-to-treat population, and the withdrawal rates (0.4% vs. 0.9%) or follow-up loss rates (1.9% vs. 1.8%) were minimal and balanced between the two comparison groups.
	Selective reporting	Low risk of bias. All of the study's pre-specified outcomes that are of interest in the review have been reported in the pre-specified manner. The study protocol is available (http://clinicaltrials.gov/show/NCT00549796)
	Other sources of bias	Low risk of bias. The study appears to be free of other sources of bias.
Jacobs, A. K. et al.	Random Sequence Generation	Low risk of bias. Randomization was performed with the use of sealed envelopes, with stratification according to hospital and history or no history of diabetes mellitus.
	Allocation concealment	Low risk of bias. Although maintaining allocation concealment of participants and medical personnel is inherently impossible since each randomized patients were transferred to other hospital or underwent on-site treatment, however, clinical outcomes were assessed by independent clinical events committee, which was blinded to the treatment received.
	Blinding of participants and personnel	Low risk of bias. The blinding of participants and medical personnel is inherently impossible since each randomized patients were transferred to other hospital or underwent on-site treatment. However, since all primary and secondary endpoints were objective findings, therefore, judged that the outcome is not likely to be influenced by lack of blinding.
	Blinding of outcome assessment	Low risk of bias. Events were adjudicated by an independent clinical events committee, whose members were unaware of the study assignments; the committee was administered by Harvard

	Clinical Research Institute.
Incomplete outcome data	Low risk of bias. All of the analyses were performed with intention-to-treat population, and 97.5% and 96.6% of both groups were included to the primary endpoints analysis.
Selective reporting	Low risk of bias. All of the study's pre-specified outcomes that are of interest in the review have been reported in the pre-specified manner. The study protocol is available (http://clinicaltrials.gov/show/NCT01116882)
Other sources of bias	Low risk of bias. The study appears to be free of other sources of bias.

Abbreviations: CVA, cerebrovascular accidents; PCI, percutaneous coronary intervention.

Supplementary Table 3. The Newcastle-Ottawa Scale for assessing the quality of 19 non-randomised studies in meta-analysis

No.	Author	Year	Selection	Comparability	Outcome
1	Dellavalle, A. et al.	1995	★★★★★	★	★
2	Weaver, W. D. et al.	1995	★★★★★	★	★★
3	Sanborn, T. A. et al.	2004	★★★★★	★	★
4	Singh, M. et al.	2004	★★★★★	★	★
5	Wennberg, D. E. et al.	2004	★★★★★	★	★
6	Ting, H. H. et al.	2006	★★★★★	★	★★
7	Carlsson, J. et al.	2006	★★★★★	★	★
8	Peels, H. O. et al.	2007	★★★	★	★
9	Shiraishi, J. et al.	2007	★★★★★	★	★
10	Frutkin, A. D. et al.	2007	★★★★★	★	★★
11	Pereira, H. et al.	2008	★★★★★	★	★
12	Hannan, E. L. et al.	2009	★★★★★	★	★★
13	Kutcher, M. A. et al.	2009	★★★★★	★	★
14	Pride, Y. B. et al.	2009	★★★★★	★	★
15	Pride, Y. B. et al.	2009	★★★★★	★	★
16	Singh, M. et al.	2009	★★★★★	★	★
17	Tebbe, U. et al.	2009	★★★★★	★	★
18	Jacek Legutko, et al.	2014	★★★★★	★	★★
19	Maddox, T. M. et al.	2014	★★★★★	★	★★

The Newcastle-Ottawa Scale	
Selection	
1.	Representativeness of the exposed cohort a) truly representative of the average _____ (describe) in the community b) somewhat representative of the average _____ in the community c) selected group of users eg nurses, volunteers d) no description of the derivation of the cohort
2.	Selection of the non exposed cohort a) drawn from the same community as the exposed cohort b) drawn from a different source c) no description of the derivation of the non exposed cohort
3.	Ascertainment of exposure to implants a) secure record (eg surgical records) b) structured interview c) written self report d) no description
4.	Demonstration that outcome of interest was not present at start of study a) yes b) no
Comparability	
1.	Comparability of cohorts on the basis of the design or analysis a) study controls for _____ (select the most important factor) b) study controls for any additional factor (This criteria could be modified to indicate specific control for a second important factor.)
Outcome	
1.	Assessment of outcome a) independent blind assessment b) record linkage c) self report d) no description
2.	Was follow up long enough for outcomes to occur a) yes b) no
3.	Adequacy of follow up of cohorts a) complete follow up - all subjects accounted for b) subjects lost to follow up unlikely to introduce bias c) follow up rate < ____% and no description of those lost d) no statement

Supplementary Figure Legends

Supplementary Figure 1. Influence of Individual Studies for All-cause Mortality, According to the Indication of Percutaneous Coronary Intervention

The circles and the horizontal lines indicate the odds ratios (by random effects model) and the 95% confidence intervals for each trial excluded.

Abbreviations: CI, confidence intervals; OR, odds ratio.

Supplementary Figure 2. Influence of Individual Studies for Emergency Surgery Rates, According to the Indication of Percutaneous Coronary Intervention

The circles and the horizontal lines indicate the odds ratios (by random effects model) and the 95% confidence intervals for each trial excluded.

Abbreviations: CI, confidence intervals; OR, odds ratio.

Supplementary Figure 3. Comparison of Early Mortality Following Percutaneous Coronary Intervention at Centers With or Without On-site Surgery

The rates of early mortality, which was defined as mortality within 30-days of index procedure, were compared between centers without on-

site surgery and with on-site surgery, according to the indication of percutaneous coronary intervention (PCI). **(A)** Primary PCI, **(B)** Non-Primary PCI. The squares and the horizontal lines indicate the odds ratio (by random effects model) and the 95% confidence intervals (CI) for each trial included; the size of each square is proportional to the statistical weight of a trial in the frequentist meta-analysis; diamond indicates the effect estimate derived from meta-analysis, with the center indicating the point estimate and the left and the right ends the 95% CI.

Abbreviations: CI, confidence interval; CS, cardiac surgery; OR, odds ratio; STEMI, ST-segment elevation myocardial infarction; NSTEMI, non ST-segment elevation myocardial infarction; PCI, percutaneous coronary intervention.

Supplementary Figure 4. Comparison of Late Mortality Following Percutaneous Coronary Intervention at Centers With or Without On-site Surgery

The rates of late mortality, which was defined as mortality after 30-days of index procedure, were compared between centers without on-site surgery and with on-site surgery, according to the indication of percutaneous coronary intervention (PCI). **(A)** Primary PCI, **(B)** Non-Primary PCI. The squares and the horizontal lines indicate the odds ratio (by random effects model) and the 95% confidence intervals (CI) for each trial included; the size of each square is proportional to the statistical weight of a trial in the frequentist meta-analysis; diamond indicates the effect estimate derived from meta-analysis, with the center indicating the point estimate and the left and the right ends the 95% CI.

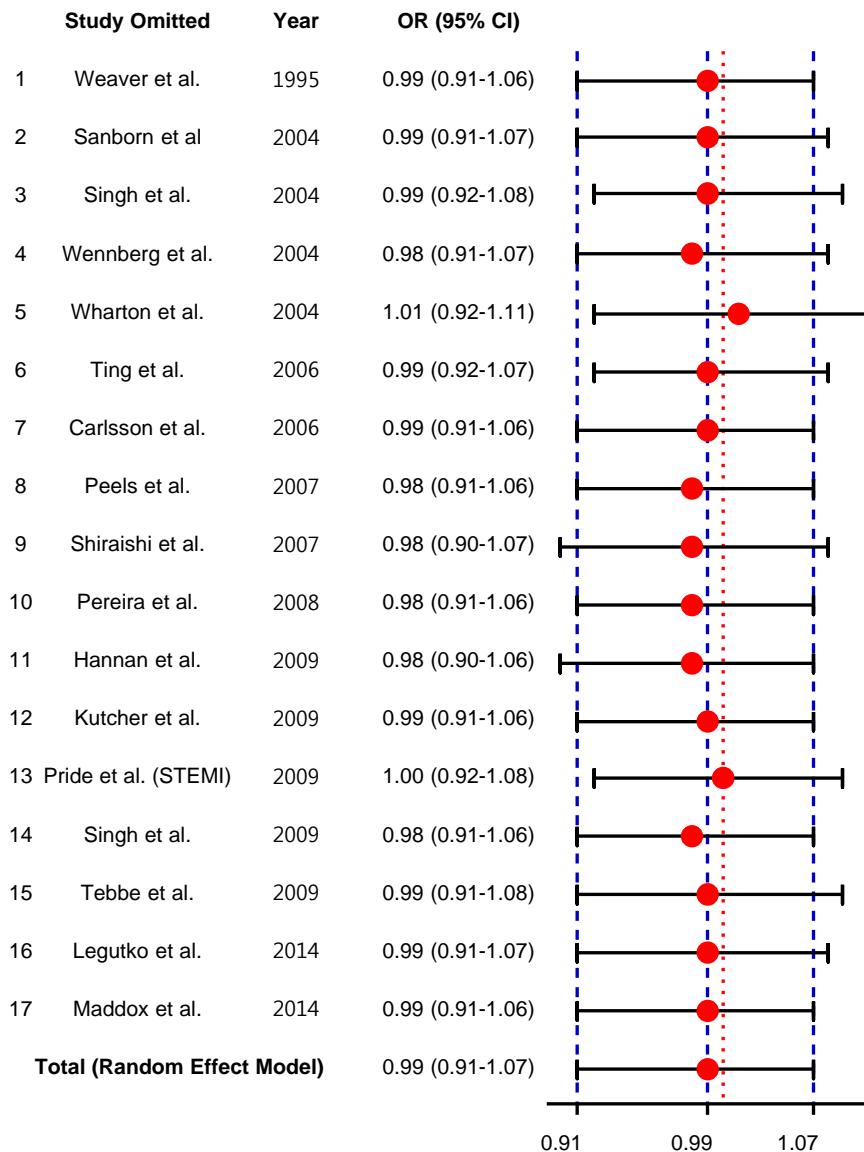
Abbreviations: CI, confidence interval; CS, cardiac surgery; OR, odds ratio; PCI, percutaneous coronary intervention.

References

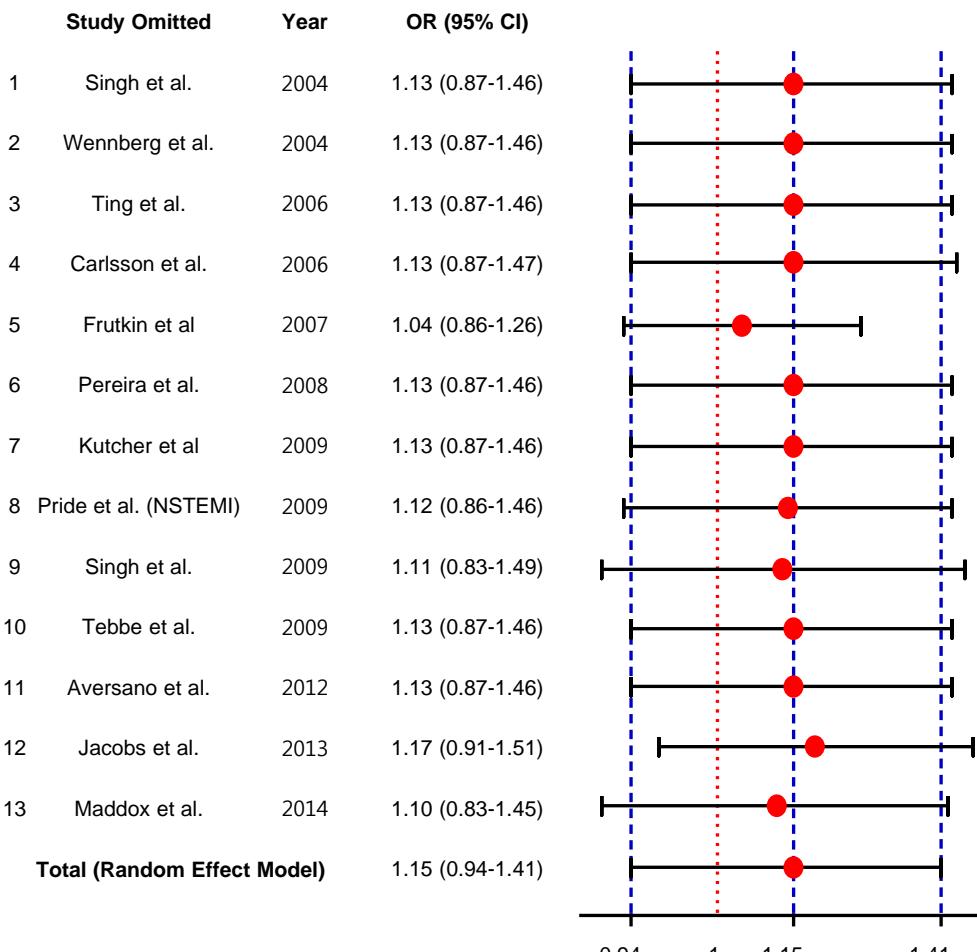
1. Normand S-LT. Tutorial in biostatistics meta-analysis: formulating, evaluating, combining, and reporting. *Statistics in medicine*. 1999;18:321-359
2. Lau J, Antman EM, Jimenez-Silva J, Kupelnick B, Mosteller F, Chalmers TC. Cumulative meta-analysis of therapeutic trials for myocardial infarction. *N Engl J Med*. 1992;327:248-254
3. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, Moher D, Becker BJ, Sipe TA, Thacker SB. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA*. 2000;283:2008-2012

Supplementary Figure 1. influence of Individual Study – All-cause Mortality

(A) Primary PCI

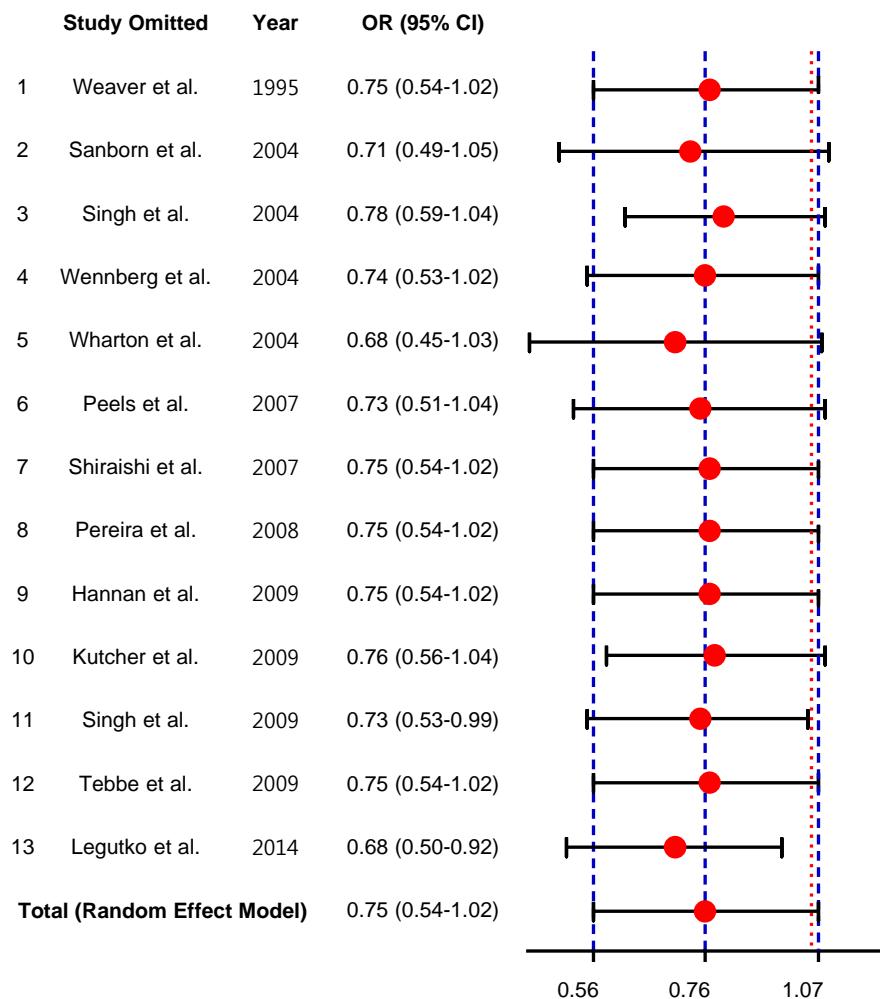


(B) Non-Primary PCI

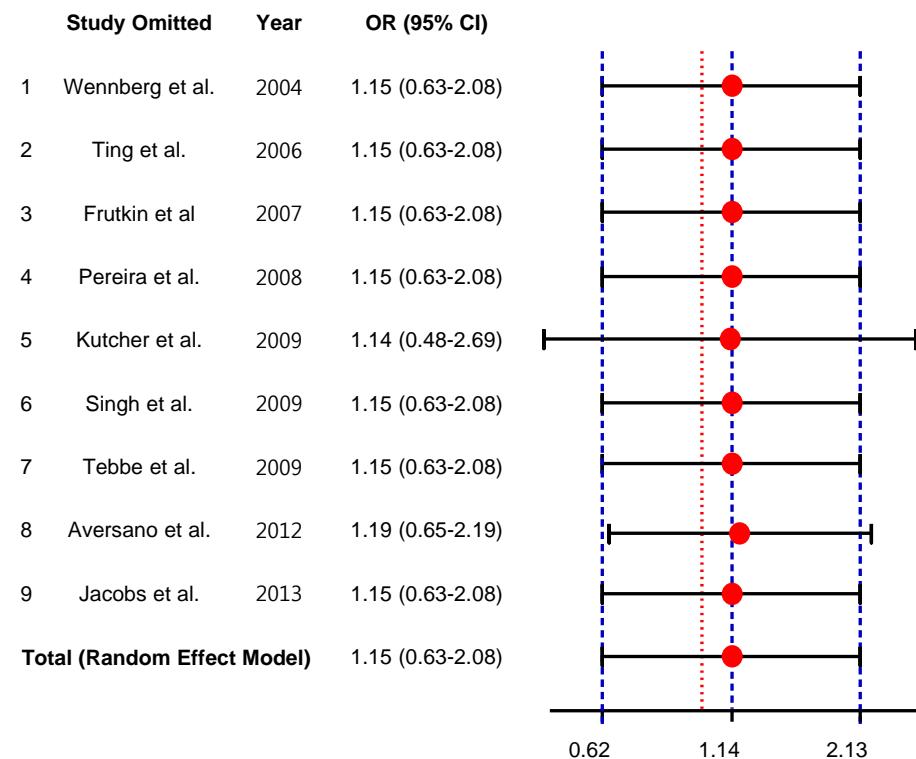


Supplementary Figure 2. influence of Individual Study – Emergency Surgery

(A) Primary PCI

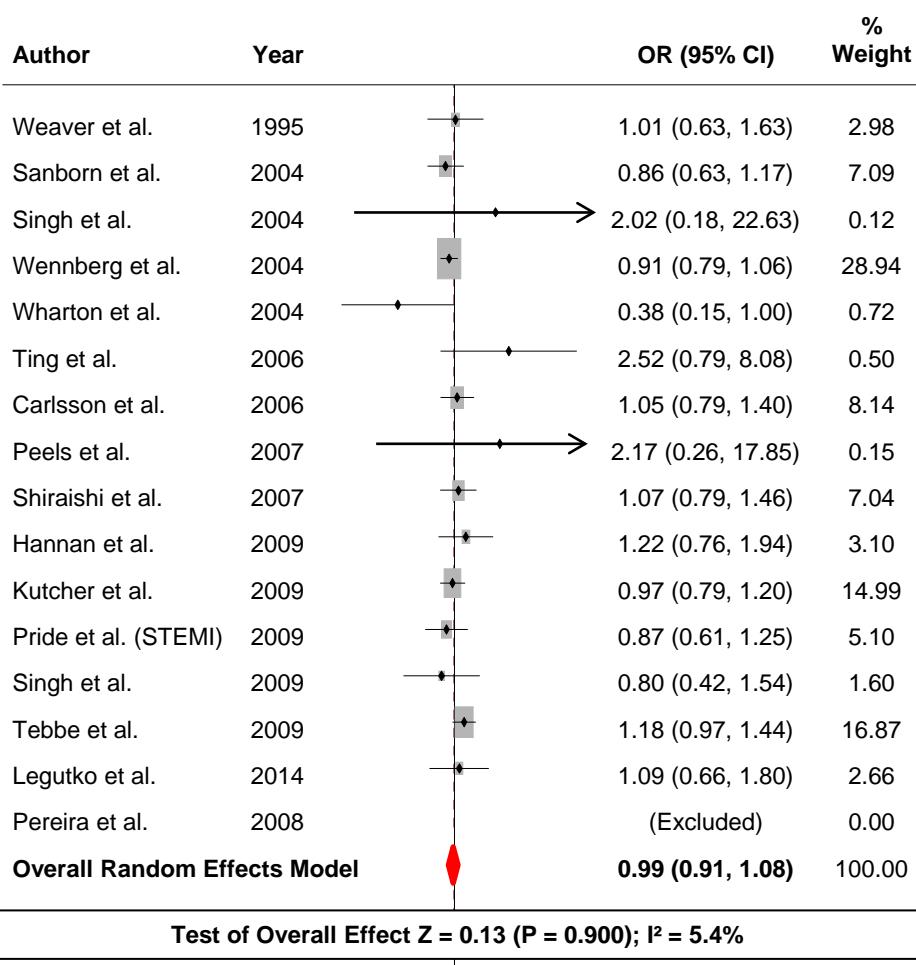


(B) Non-Primary PCI

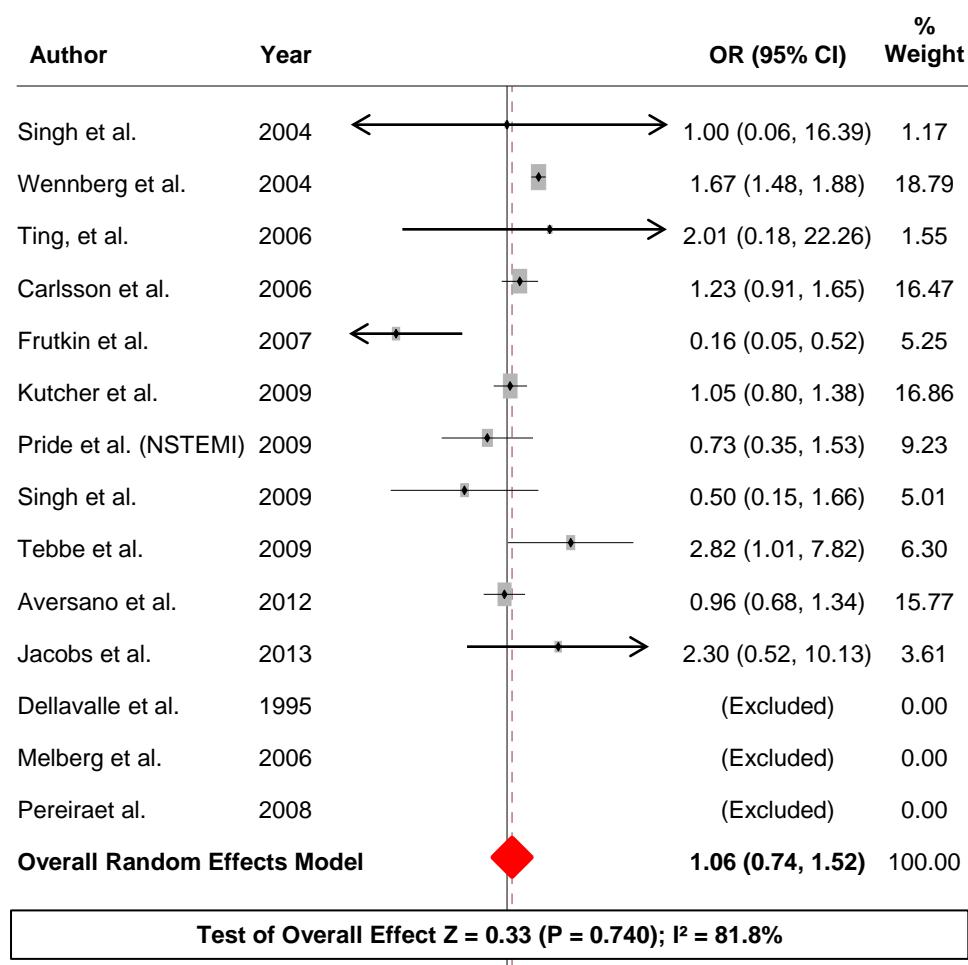


Supplementary Figure 3. All-Cause Mortality Within 30-day

(A) Primary PCI

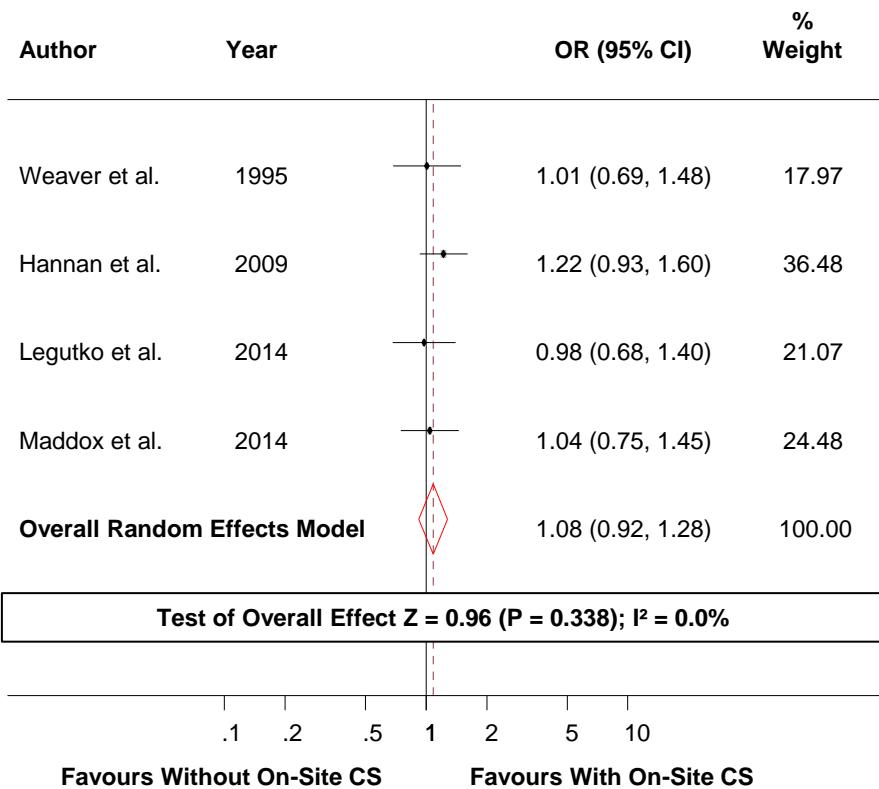


(B) Non-Primary PCI

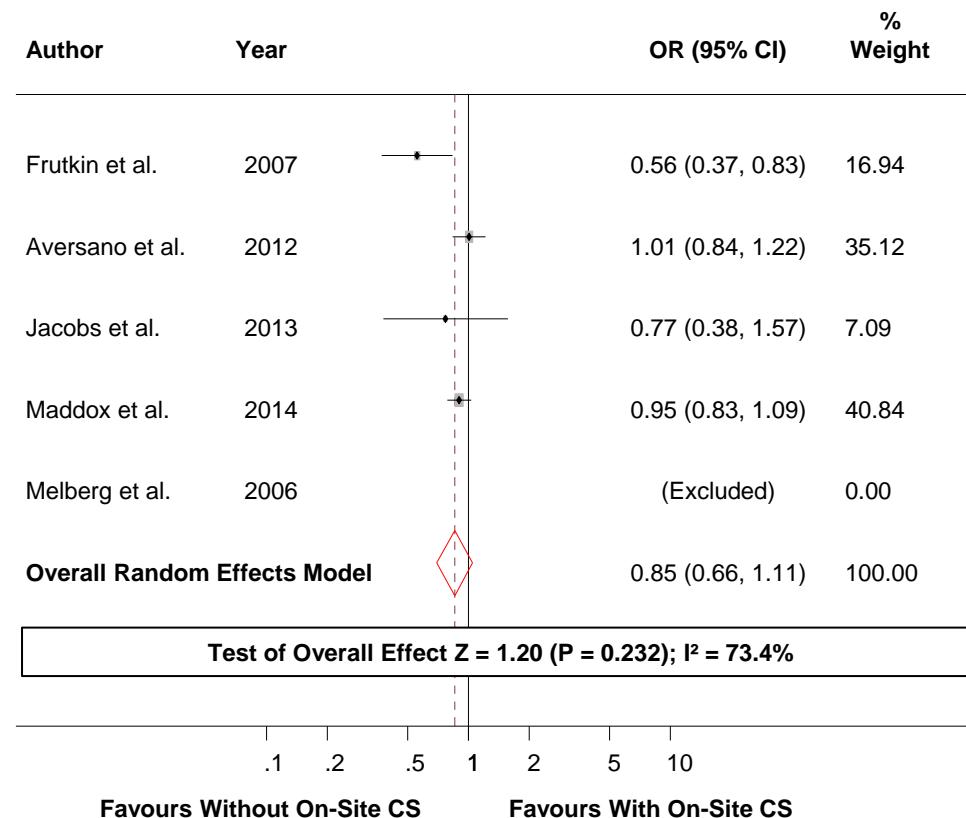


Supplementary Figure 4. All-Cause Mortality After 30-day

(A) Primary PCI



(B) Non-Primary PCI



Percutaneous Coronary Intervention at Centers With and Without On-Site Surgical Backup: An Updated Meta-Analysis of 23 Studies

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