

Clinical outcomes of COMBO dual-therapy stents versus contemporary drug-eluting stents: a meta-analysis of randomized trials

Ming Fan

Yueyang Hospital of Integrated of Traditional Chinese and Western Medicine, Shanghai University of Traditional Chinese Medicine

Feng Wu

wufeng@shyueyanghospital.com

Yueyang Hospital of Integrated of Traditional Chinese and Western Medicine, Shanghai University of Traditional Chinese Medicine

Ming Shen

Yueyang Hospital of Integrated of Traditional Chinese and Western Medicine, Shanghai University of Traditional Chinese Medicine

Hui-huan Yuan

Yueyang Hospital of Integrated of Traditional Chinese and Western Medicine, Shanghai University of Traditional Chinese Medicine

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Abstract

Background

The COMBO dual-therapy stent combines sirolimus elution with endothelial progenitor cell capture to promote vascular healing. Whether this design translates into better clinical outcomes than contemporary drug-eluting stents (DES) remains uncertain.

Methods

This meta-analysis was registered in PROSPERO (CRD420251062728). PubMed, Embase, Web of Science, and the Cochrane Library were searched for randomized controlled trials (RCTs) comparing COMBO stents with standard DES. The primary outcome was target lesion failure (TLF). Risk ratios (RRs) were pooled with a random-effects model. Prespecified leave-one-out sensitivity analyses were used to explore trial-level heterogeneity.

Results

Six RCTs (8 reports) involving 7,527 patients were included. In the primary pooled analysis, COMBO stents were associated with higher risks of 1-year TLF (RR 1.41, 95% CI 1.16–1.72; $P = 0.0006$) and all-cause mortality (RR 1.42, 95% CI 1.04–1.93; $P = 0.03$). However, both signals were entirely driven by a single large trial (SORT OUT X); after exclusion of this trial, no significant between-group differences remained for any 1-year endpoint. At long-term follow-up (≥ 2 years), apparent increases in TLF, target lesion revascularization, and target vessel revascularization were again driven primarily by SORT OUT X and disappeared after sensitivity analysis.

Conclusion

Current randomized evidence does not support a definitive conclusion regarding the comparative efficacy or safety of COMBO stents versus standard DES. Apparent risk signals are highly dependent on a single trial, limiting their generalizability. Additional adequately powered RCTs are needed to clarify the clinical role of COMBO stents.

1. Introduction

Coronary artery disease (CAD) remains a leading cause of death and disability worldwide[1]. Percutaneous coronary intervention (PCI), a cornerstone therapy for CAD, has undergone substantial technological evolution over the past decades. Since the first successful PCI performed by Andreas Gruentzig in 1977, coronary stent technology has progressed from bare-metal stents (BMS) to drug-eluting stents (DES)[2]. Although BMS significantly reduced the risk of acute vessel occlusion, high rates

of restenosis (17–41%) limited their long-term efficacy[3–5]. The subsequent development of DES, incorporating antiproliferative drug coatings, markedly reduced restenosis rates to less than 10%, establishing them as the standard of care for coronary revascularization[6, 7]. However, in-stent restenosis (ISR) and stent thrombosis (ST) remain the major concerns that continue to affect long-term outcomes of DES[8]. Although the incidence of late and very late ST is low, these events may result in severe consequences, including myocardial infarction (MI) and death[9].

To address these limitations, novel stent platforms have been developed with the aim of improving endothelial healing without sacrificing antiproliferative efficacy. The COMBO dual-therapy stent (OrbusNeich Medical, Ft. Lauderdale, Florida) is a sirolimus-eluting stent with an anti-CD34 antibody coating designed to capture circulating endothelial progenitor cells (EPCs). This dual mechanism aims to inhibit neointimal hyperplasia while promoting endothelial healing[10]. Several randomized controlled trials (RCTs) have evaluated the clinical performance of the COMBO stent compared with contemporary DES. However, their findings have been inconsistent, and some studies were limited by sample size or specific patient populations[11–18]. Therefore, we conducted a systematic review and meta-analysis of RCTs to comprehensively evaluate the efficacy and safety of the COMBO stent compared with standard DES, with a particular focus on identifying potential sources of heterogeneity across trials.

2. Methods

This meta-analysis was conducted in accordance with the Cochrane Handbook for Systematic Reviews of Interventions[19] and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[20]. The study protocol was prospectively registered in PROSPERO (CRD420251062728).

2.1 Search strategy

A systematic literature search was independently performed by two reviewers (M.S. and H.Y.) in PubMed, Embase, Web of Science, and the Cochrane Library from inception to August 2025. The search strategy combined Medical Subject Headings (MeSH) and free-text terms related to “drug-eluting stents,” “COMBO stent,” and “coronary artery disease.” The full search strategies for each database are provided in Supplementary Table S1.

2.2 Eligibility criteria

Studies were included if they met the following criteria: (1) randomized controlled trial design; (2) direct comparison between COMBO stents and standard DES; (3) follow-up duration of at least 12 months; and (4) reporting of at least one prespecified clinical outcome. Studies were excluded if they were non-randomized, lacked a control group, involved additional interventions beyond stent implantation, or did not provide sufficient outcome data.

2.3 Outcomes

The primary endpoint was target lesion failure (TLF), defined as a composite of cardiac death, target vessel myocardial infarction, or clinically driven target lesion revascularization. Secondary endpoints included target lesion revascularization (TLR), target vessel revascularization (TVR), all-cause mortality, cardiac death, myocardial infarction, and stent thrombosis.

2.4 Study selection, data extraction, and quality assessment

Study selection and data extraction were independently performed by two reviewers (M.S. and H.Y.) Discrepancies were resolved through discussion and consensus. The study selection process is summarized in the PRISMA flow diagram (Fig. 1). The risk of bias of included RCTs was assessed using the Cochrane RoB 2 tool[21]. Each study was evaluated across domains including randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selection of reported results.

2.5 Statistical analysis

Statistical analyses were performed using RevMan (version 5.4.1) and Stata (version 14). Risk ratios (RR) with 95% confidence intervals (CI) were used as effect measures. Between-study heterogeneity was assessed using the Higgins I^2 statistic. A random-effects model was applied to account for potential heterogeneity across studies. Prespecified sensitivity analyses were conducted by sequentially excluding individual trials to evaluate the robustness of pooled estimates and to identify potential sources of heterogeneity. Publication bias was assessed using Egger's test. When potential bias was detected ($P < 0.1$), the trim-and-fill method was applied to evaluate its impact on the pooled results.

3. Results

3.1 Study selection and characteristics

As shown in the PRISMA flow diagram (Fig. 1), 307 records were initially identified (PubMed, 72; Web of Science, 163; Embase, 48; Cochrane Library, 24). After deduplication, 177 remained. Of these, 132 were excluded at title/abstract screening, and 45 underwent full-text assessment. Ultimately, 8 reports from 6 RCTs were included. In total, 7,527 patients were analyzed, including 3,803 assigned to the COMBO group and 3,724 to the standard DES group. The characteristics of the included studies are summarized in Table 1.

Table 1
Baseline characteristics of included studies

Study	Author	Year	Follow-up	COMBO (n)	Total (n)	Study population	DES type
REMEDEE	Haude et al	2013	1 year; 5 years	124	183	De novo native coronary artery lesions	PES
REMEDEE-OCT	Jaguszewski et al	2017	1 year	28	58	ACS	EES
HARMONEE	Saito et al	2018	1 year	287	572	Ischemic coronary disease; Non-ST ACS	EES
SORT OUT X	Jakobsen et al	2021	1 year; 3 years	1578	3146	All-comer patients undergoing PCI for CAD	SES
RECOVERY	Tao et al	2021	1 year; 2 years	216	432	De novo native coronary artery lesions	SES
SORT OUT XI	Eftekhari et al	2025	1 year	1570	3136	All-comer patients undergoing PCI for CAD	BES
DES, drug-eluting stents; PES, paclitaxel-eluting stent; ACS, acute coronary syndrome; EES, everolimus-eluting stent; Non-ST ACS, non-ST-elevation acute coronary syndrome; CAD, coronary artery disease; SES, sirolimus-eluting stent; BES, biolimus-eluting stent; PCI, percutaneous coronary intervention.							

3.2 Risk of bias assessment

The RoB 2 assessment showed low risk of bias for deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting across all included trials. Three studies (REMEDEE, REMEDEE-OCT, and RECOVERY) were judged to have some concerns in the randomization domain because insufficient detail was provided on sequence generation or allocation concealment (Supplementary Fig. S1). Overall, the included trials were considered methodologically sound.

3.3 Clinical outcomes at 1-year follow-up

All six RCTs contributed 1-year outcome data. In the initial pooled analysis, the COMBO group had a higher risk of 1-year TLF than the standard DES group (RR 1.41, 95% CI 1.16–1.72; $P < 0.001$; Fig. 2A). Sensitivity analysis showed that this result was driven largely by SORT OUT X (weight 38.8%); after exclusion of that trial, the difference was no longer statistically significant (Fig. 4A). A similar pattern was observed for 1-year all-cause mortality (RR 1.42, 95% CI 1.04–1.93; $P = 0.03$; Fig. 3A), for which SORT OUT X contributed 50.4% of the weight, and the pooled association disappeared after exclusion of

that study (Fig. 4D). No significant differences were observed for 1-year TLR, TVR, cardiac death, myocardial infarction, or stent thrombosis (Figs. 2B-2C and 3B-3D), and these null findings remained stable in sensitivity analyses (Fig. 4B-4C and 4E-4G).

Exploratory Egger's test suggested possible small-study effects for 1-year all-cause mortality (Supplementary Table S2), and trim-and-fill did not materially change the pooled estimate (Supplementary Table S3). Given the small number of studies and the loss of significance in sensitivity analysis, this signal should be interpreted cautiously.

3.4 Clinical outcomes at long-term (≥ 2 years) follow-up

At long-term follow-up (≥ 2 years), the preliminary pooled analysis suggested higher risks of TLF (RR 1.26, 95% CI 1.03–1.55; $P = 0.02$; Fig. 5A), TLR (RR 1.37, 95% CI 1.01–1.84; $P = 0.04$; Fig. 5B), and TVR (RR 1.28, 95% CI 1.01–1.64; $P = 0.04$; Fig. 5C) with COMBO stents. However, each of these signals was dominated by the 3-year SORT OUT X report; once that trial was removed, none of the associations remained significant (Fig. 7A-7C). No significant between-group differences were observed for long-term all-cause mortality, cardiac death, myocardial infarction, or stent thrombosis, and these findings were stable in sensitivity analyses (Fig. 6A-6D and 7D-7G). No clear publication-bias signal was detected for the long-term outcomes, although these analyses should be interpreted cautiously because few studies were available (Supplementary Table S4).

4. Discussion

The principal finding of this meta-analysis is the identification of a trial-driven effect underlying the apparent differences in clinical outcomes between COMBO stents and contemporary DES. Although pooled analyses suggested increased risks of adverse outcomes, these signals were entirely dependent on a single large randomized trial (SORT OUT X). Importantly, all differences disappeared after prespecified sensitivity analyses. Therefore, current randomized evidence does not support a definitive conclusion regarding the relative efficacy or safety of the COMBO stent.

The disproportionate influence of the SORT OUT X trial warrants careful interpretation. This study contributed a large proportion of the overall sample size and employed an all-comer design, enrolling a broader and more heterogeneous population than other trials[15]. In addition, differences in comparator stent platforms may have influenced the observed outcomes. These factors highlight the potential impact of clinical and methodological heterogeneity when a single trial dominates pooled estimates.

After accounting for the dominant trial, no significant differences were observed across any clinical endpoints. This suggests that the theoretical advantages of EPC-capture technology have not consistently translated into measurable clinical benefit in randomized settings[22, 23]. In patients with coronary artery disease, circulating EPCs are often quantitatively reduced and functionally impaired, which may diminish the efficacy of the anti-CD34 antibody coating[24, 25]. Substantial clinical evidence, including multiple meta-analyses, has consistently demonstrated that ultrathin stent struts ($< 70\text{--}80\text{ }\mu\text{m}$)

accelerate endothelial coverage, reduce vascular injury, and lower the risks of stent thrombosis and restenosis[26–28]. The lack of observed theoretical benefit with the COMBO stent may largely be attributable to the physical disadvantage imposed by its relatively thick struts (100 µm)[24]. This suggests that within contemporary stent technology, optimized physical design, particularly ultrathin struts, may exert a more decisive and immediate effect on inhibiting neointimal hyperplasia than the COMBO stent's unique biological pro-healing mechanism.

The observed increase in 1-year all-cause mortality should be interpreted with caution. This signal was entirely driven by the SORT OUT X trial and was no longer present after sensitivity analysis. Moreover, no difference in mortality was observed at long-term follow-up. One possible explanation is that the COMBO stent may confer an “early hazard,” potentially associated with increased vascular injury or inflammatory response during the acute phase, attributable to its relatively thick struts[28, 29]. However, as its biological pro-healing mechanisms (e.g., late neointimal regression) begin to exert their effect, this early risk may be progressively attenuated over time[30]. Taken together, these findings do not support a consistent or robust safety signal.

Real-world registry studies have reported acceptable safety and efficacy profiles for the COMBO stent. In the large prospective “all-comer” registry studies REMEDEE and MASCOT, the COMBO stent demonstrated favorable clinical safety and efficacy. The 1-year TLF rate (3.9%) and 5-year definite/probable ST rate (0.9%) were low, with late ST events being rare[31, 32]. However, differences in study design, the absence of randomized comparators, and potential confounding limit direct comparison with RCT-based findings. This discrepancy further underscores the need for cautious interpretation of comparative effectiveness. Therefore, a balanced appraisal of the COMBO stent is that it represents a safe and effective device, yet its unique “dual-therapy” concept may not be sufficient to consistently outperform contemporary competitors with more advanced physical designs across all clinical endpoints.

From a clinical perspective, the current evidence base supports a cautious rather than a dismissive interpretation. The observed adverse signals cannot be ignored, but they also cannot be considered definitive because they depend heavily on a single trial. Accordingly, clinicians should avoid overinterpreting either the preliminary pooled estimates or the null sensitivity analyses. Instead, the available data indicate uncertainty, particularly when COMBO is compared with high-performing contemporary DES in broad all-comer populations.

This study has several strengths. It includes only randomized controlled trials and applies prespecified sensitivity analyses to systematically explore sources of heterogeneity. Notably, the identification of a trial-driven effect provides insight beyond conventional pooled estimates. Several limitations should also be acknowledged. First, the available evidence is heavily influenced by a single large trial, which limits the robustness of pooled conclusions. Second, heterogeneity in comparator stents and patient populations may have introduced variability. Third, the lack of individual patient data precluded subgroup analyses and adjustment for clinical covariates.

5. Conclusions

In conclusion, current randomized evidence does not support a definitive superiority or inferiority of COMBO dual-therapy stents compared with standard DES. Apparent adverse signals in the primary pooled analyses were highly dependent on a single large trial and therefore should not be generalized uncritically. Further adequately powered randomized studies, ideally using clearly defined contemporary comparators and longer follow-up, are needed to define the clinical role of COMBO stents.

Declarations

Declaration of competing interest

The authors declare no conflict of interest.

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Author Contribution

MS and HHY conceived and designed the study: MS and HHY conducted the literature search and screening and data extraction. MS conducted the statistical analyses and wrote the first draft of the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Data Availability

The datasets generated and analysed during the current study are not publicly available due to the administrative requirements of Yueyang Hospital of Integrated of Traditional Chinese and Western Medicine Shanghai University of Traditional Chinese Medicine, but are available from the corresponding author on reasonable request.

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Figures

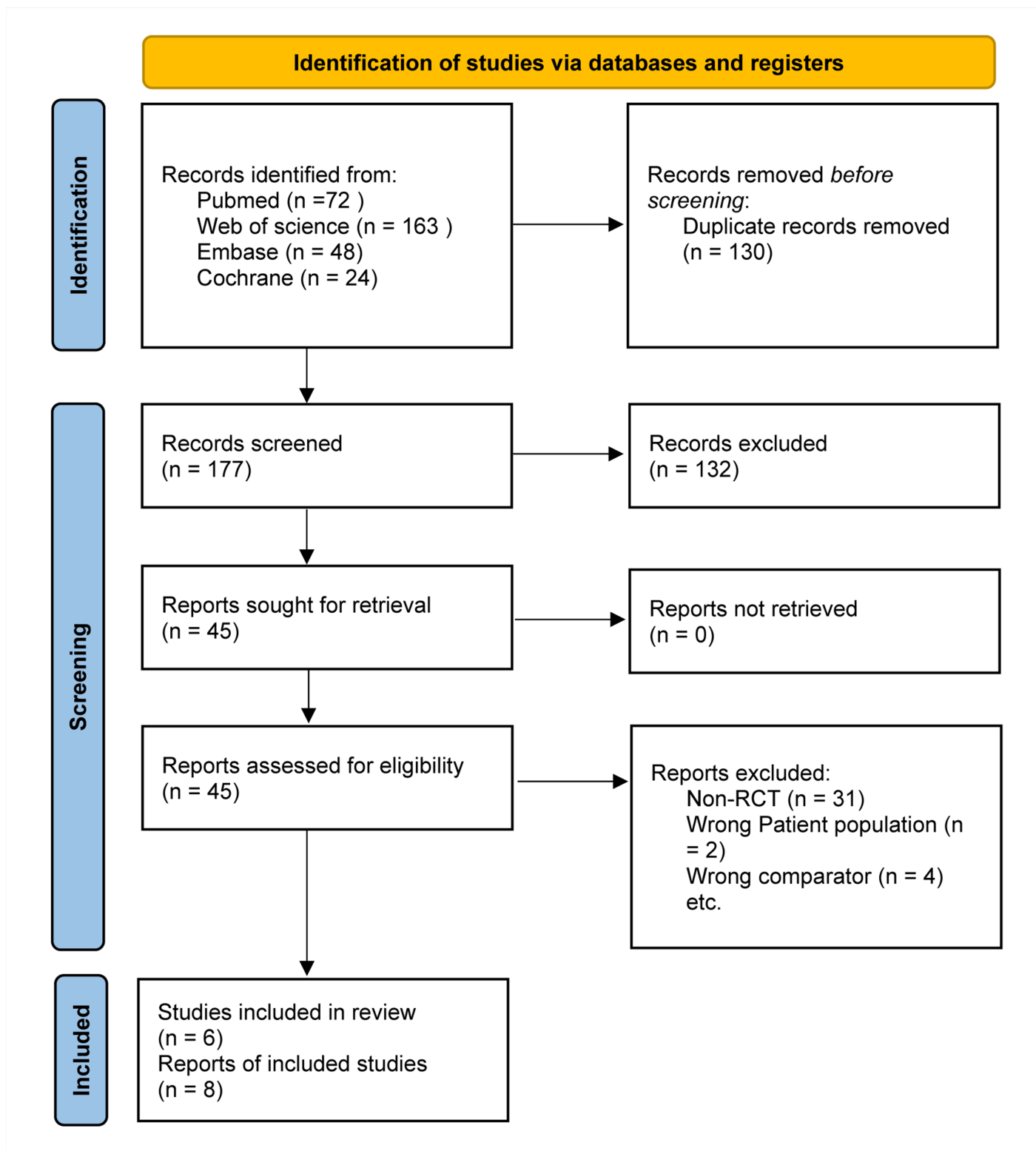


Figure 1

PRISMA flowchart.

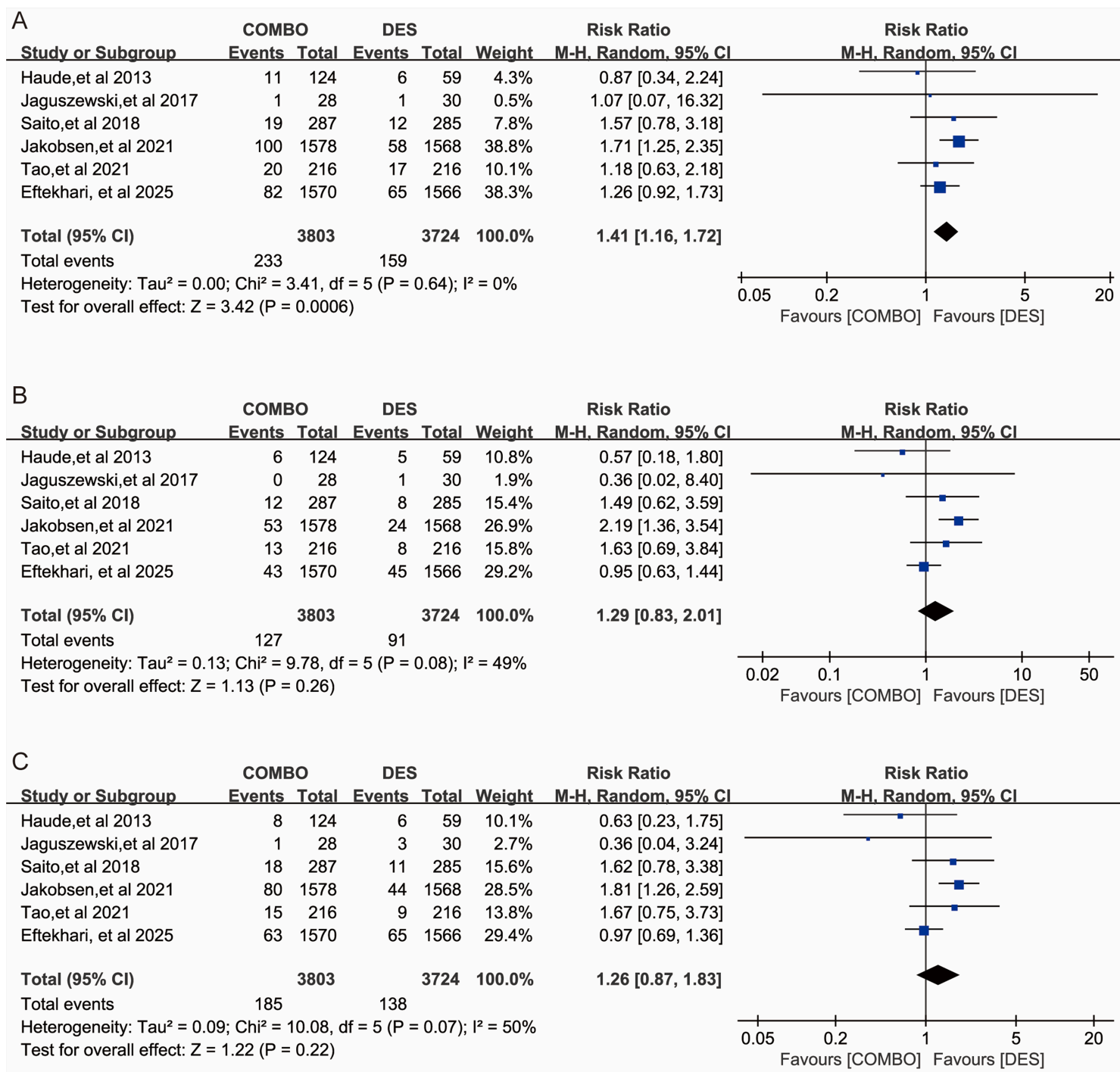


Figure 2

Forest plot of 1-year TLF, TLR and TVR. (A)TLF. (B)TLR. (C)TVR. DES, drug-eluting stents; TLF, target lesion failure; TLR, target lesion revascularization; TVR, target vessel revascularization.

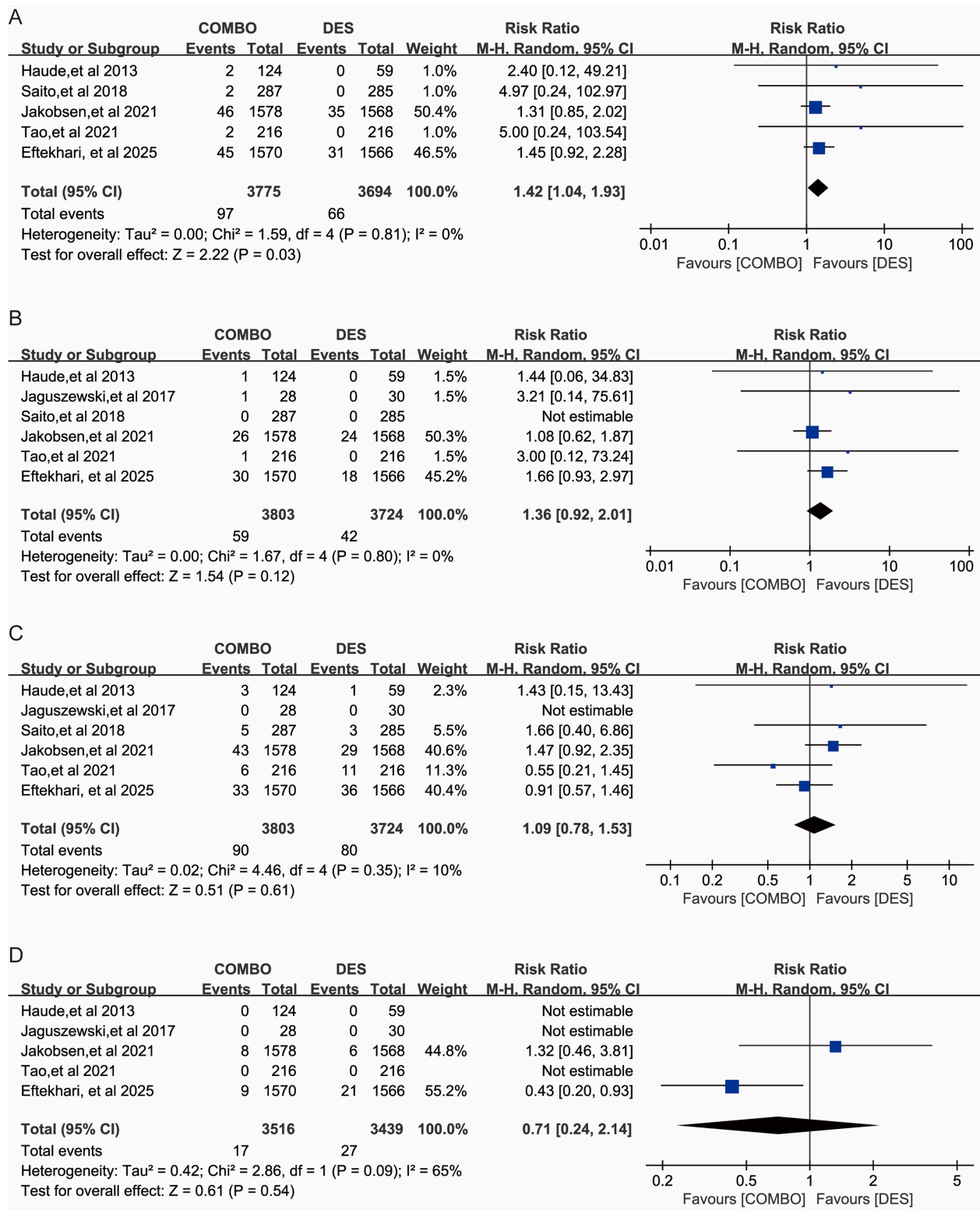


Figure 3

Forest plot of 1-year all-cause mortality, cardiac death, MI and ST. (A) All-cause mortality. (B) Cardiac death. (C) MI. (D) ST. DES, drug-eluting stents; MI, myocardial infarction; ST, stent thrombosis.

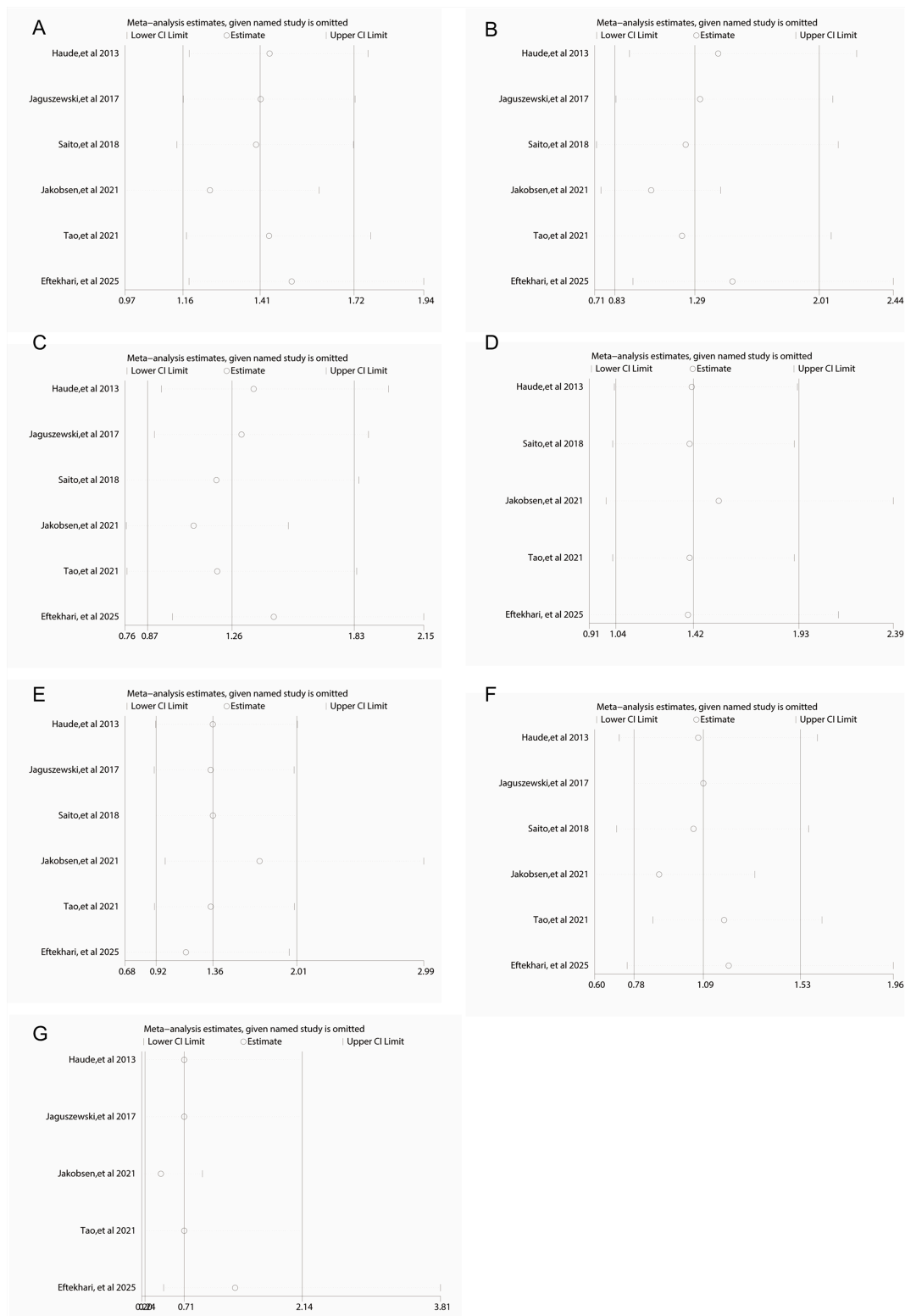


Figure 4

Sensitivity analysis of 1-year clinical outcomes. (A)TLF. (B)TLR. (C)TVR. (D) All-cause mortality. (E) Cardiac death. (F) MI. (G) ST. TLF, target lesion failure; TLR, target lesion revascularization; TVR, target vessel revascularization; MI, myocardial infarction; ST, stent thrombosis.

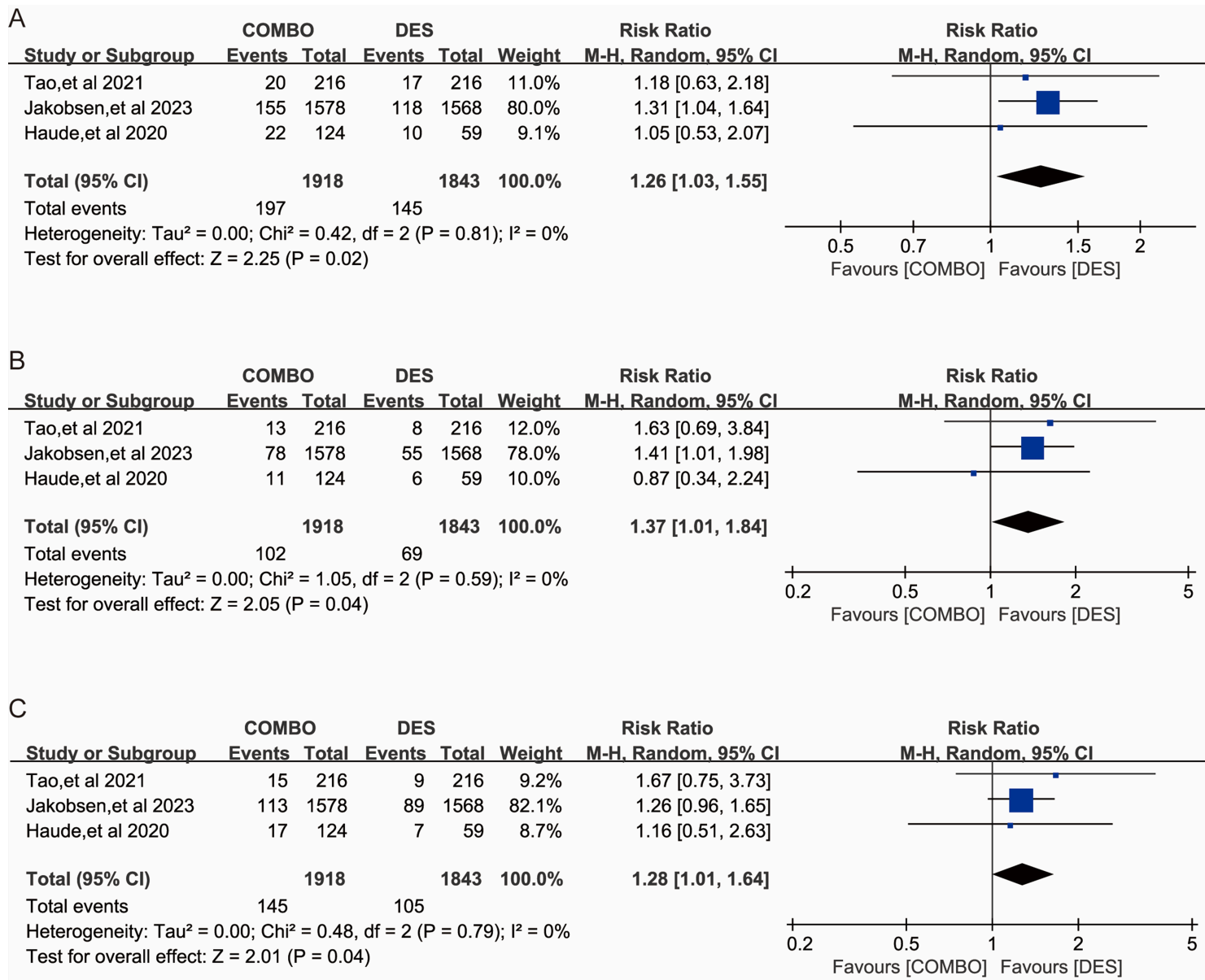


Figure 5

Forest plot of long-term (≥ 2 years) TLF, TLR and TVR. (A)TLF. (B)TLR. (C)TVR. DES, drug-eluting stents; TLF, target lesion failure; TLR, target lesion revascularization; TVR, target vessel revascularization.

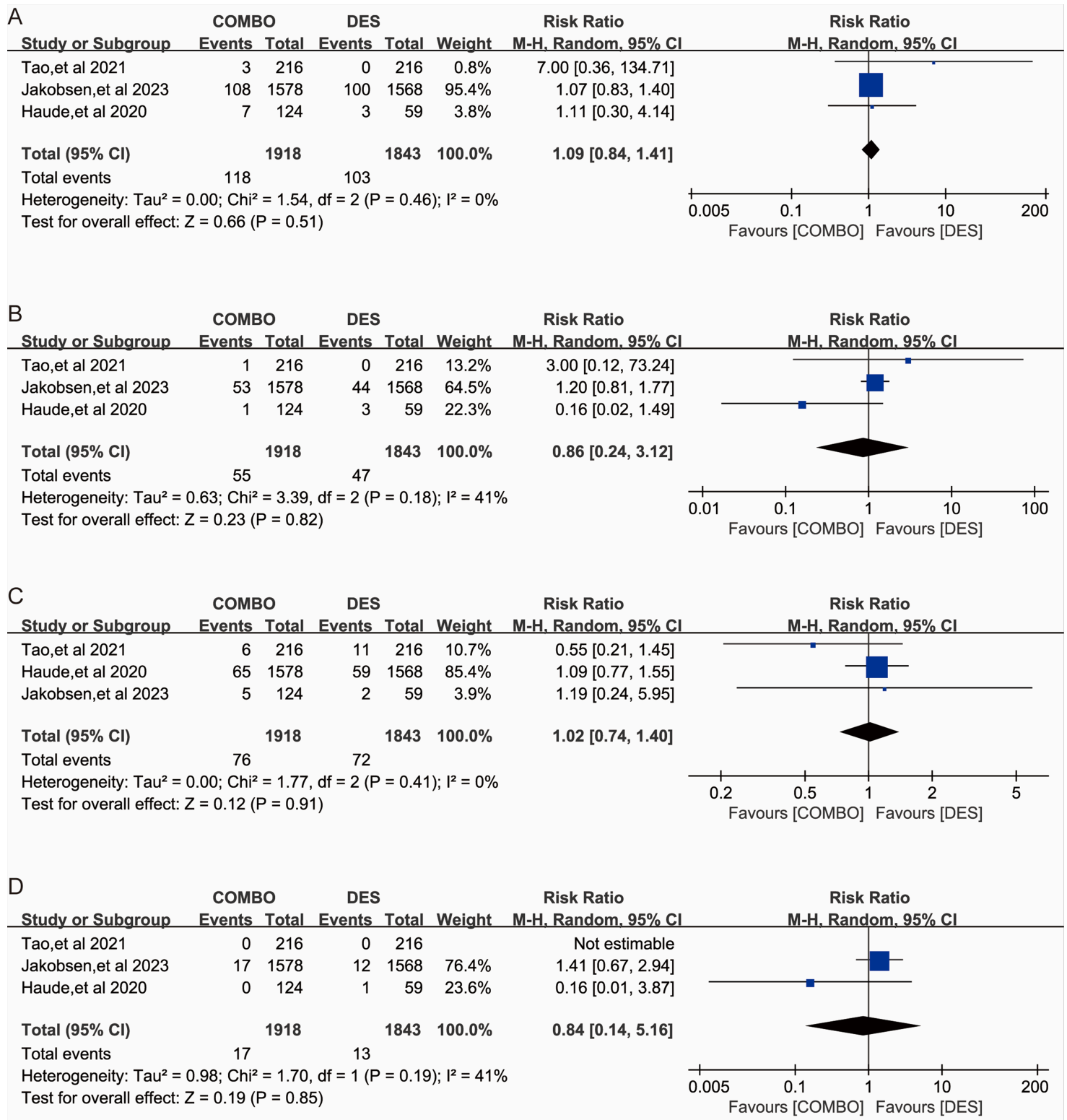


Figure 6

Forest plot of long-term (≥ 2 years) all-cause mortality, cardiac death, MI and ST. (A) All-cause mortality. (B) Cardiac death. (C) MI. (D) ST. DES, drug-eluting stents; MI, myocardial infarction; ST, stent thrombosis.

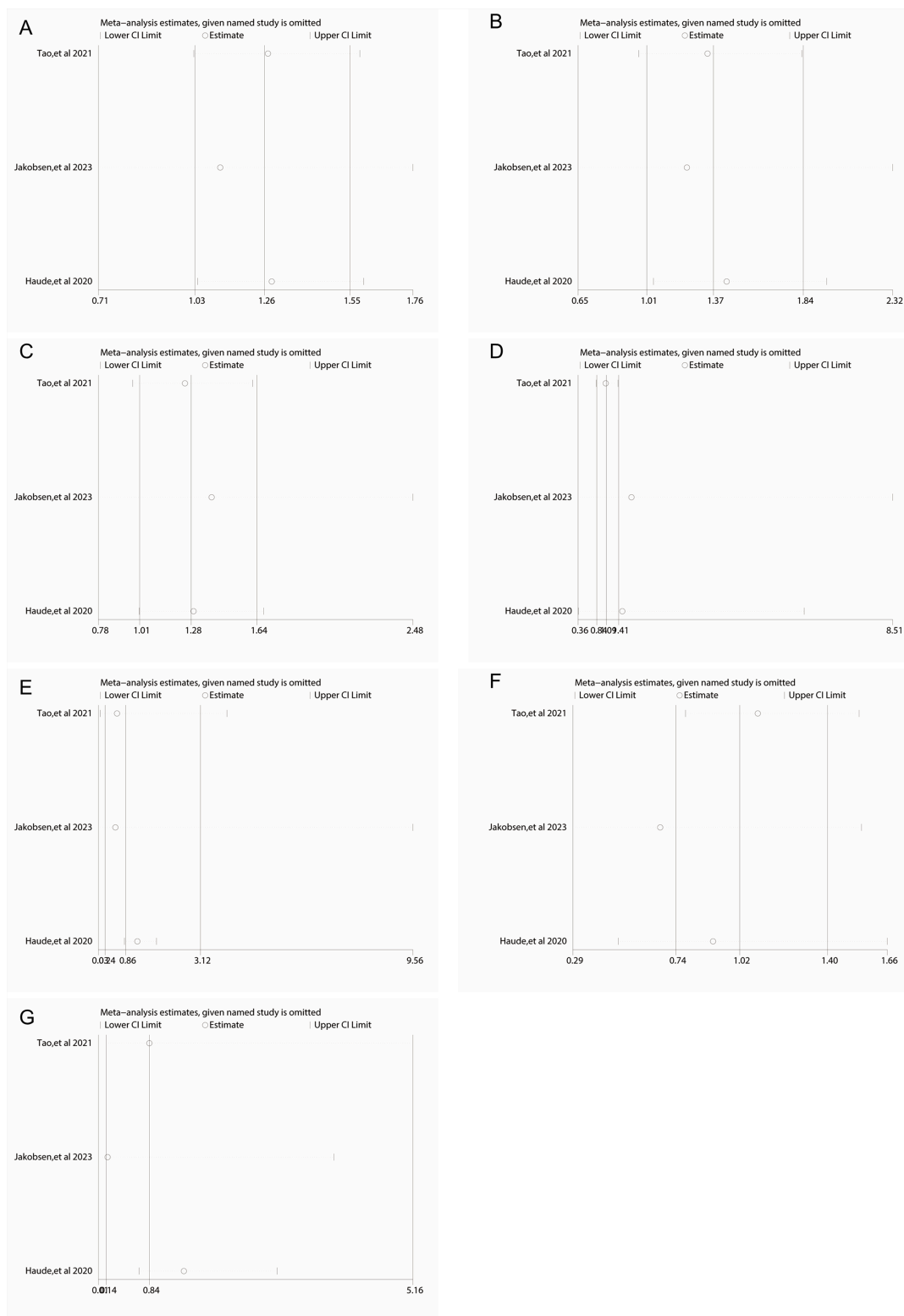


Figure 7

Sensitivity analysis of long-term (≥ 2 years) clinical outcomes. (A) TLF. (B) TLR. (C) TVR. (D) All-cause mortality. (E) Cardiac death. (F) MI. (G) ST. TLF, target lesion failure; TLR, target lesion revascularization; TVR, target vessel revascularization; MI, myocardial infarction; ST, stent thrombosis.

Supplementary Files

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