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ORIGINAL PAPER

Intravascular ultrasound guidance reduces cardiac death and coronary revascularization in patients undergoing drug-eluting stent implantation: results from a meta-analysis of 9 randomized trials and 4724 patients

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Abstract

Intravascular ultrasound (IVUS) guidance is not routinely performed in real-word clinical practice partly because the benefit of IVUS guidance is not well established. This updated meta-analysis aims to compare IVUS-guided and angiography-guided drug-eluting stent (DES) implantation, simultaneously stressing the value of an optimal IVUS-defined procedure. Medline, Scopus, Google Scholar, and Cochrane Controlled Trials Registry were searched for the randomized trials comparing IVUS-guided and angiography-guided DES implantation. Nine eligible randomized trials including 4,724 patients were identified. At a mean follow-up of 16.7 months, IVUS guidance was associated with a significant lower risk of major adverse cardiovascular events (MACE) [5.4% vs. 9.0%; relative risks (RR): 0.61, 95% confident interval (CI) 0.49–0.74, $p < 0.001$], cardiac death (0.6% vs. 1.2%; RR: 0.49, 95% CI 0.26–0.92, $p = 0.03$), target vessel revascularization (3.5% vs .6.1%; RR: 0.58, 95% CI 0.42–0.80, $p = 0.001$), target lesion revascularization (3.1% vs. 5.2%; RR: 0.59, 95% CI 0.44–0.80, $p = 0.001$), and definite/probable stent thrombosis (0.5% vs .1.1%; RR: 0.45, 95% CI 0.23–0.87, $p = 0.02$) compared with angiography guidance. No significant differences in all cause death and myocardial infarction were noted between the two groups. Subgroup analysis showed that patients who met the optimal criteria had a lower rate of MACE than those with IVUS-defined suboptimal procedure (RR: 0.33, 95% CI 0.06–0.60, $p = 0.02$). The present meta-analysis with the largest sample size to date demonstrates that IVUS-guided DES implantation significantly reduces cardiac death, coronary revascularization and stent thrombosis, particularly for patients with IVUS-defined optimal procedures compared with angiography guidance.

Keywords Intravascular ultrasound · Angiography · Drug-eluting stents · Optimal criteria · Meta-analysis

Introduction

Intravascular ultrasound (IVUS) with a high spatial resolution is a useful tool for evaluating lesion morphology and optimizing stent implantation. In the bare metal stent (BMS) era, the clinical benefit of IVUS-guided percutaneous coronary intervention (PCI) was largely driven by reductions in restenosis and target vessel revascularization (TVR) without significant benefits in death or myocardial infarction [1].

Drug-eluting stents (DES) are superior to BMS in terms of a reduced rate of stent restenosis less than 10% [2]. In the DES era, the common changes of IVUS-guided DES implantation include larger size stents/balloons, longer stents, and more frequent postdilation, which could lead to a larger postprocedural minimal lumen diameter (MLD)

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and subsequently reduced adverse cardiovascular events [3]. Several registries [4–8], randomized controlled trials (RCTs) [9–14] and meta-analyses [3, 15–17] have confirmed these results and demonstrated that IVUS-guided DES implantation was associated with the reduction of major adverse cardiac events (MACE) and TVR in complex lesions (long lesions, bifurcation lesions, chronic total occlusion, and unprotected left main disease). Notably, the ULTIMATE trial [18] (comparison of intravascular ultrasound-guided vs. angiography-guided implantation of drug-eluting stent in all-comers) recently demonstrated that IVUS-guided DES implantation could significantly reduce target vessel failure (TVF) in all-comers, particularly patients with IVUS-defined optimal procedure, compared with angiography guidance. However, IVUS-guided procedure is not routinely performed in real-world clinical practice partly due to the increased procedural time and expense as well as a neutral effect on cardiac death. Therefore, the present updated meta-analysis including the latest ULTIMATE trial was designed to confirm the benefit of IVUS-guided over angiography-guided DES implantation.

Materials and methods

Literature search

Clinical studies comparing IVUS-guided and angiography-guided DES implantation were acquired by searching Medline, Google Scholar, Scopus, and Cochrane Controlled Trials Registry from January 2005 to October 2018. The combinations of various keywords and Medical Subject Heading, "(randomized controlled trial or controlled clinical trial or randomized or randomly) and (angiography or angiography-guided or angio-guided) and (IVUS or intravascular ultrasound or IVUS-guided or ultrasound-guided) and (percutaneous coronary intervention or PCI or stenting or stent or coronary stenting)", were used to search and enroll all relevant studies. References from reviews, selected articles and previous meta-analyses [3, 15–17, 19, 20] were also screened.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) randomized comparison between IVUS guidance and angiography guidance; (2) only DES implantation; (3) at least 1-year clinical follow-up. The exclusion criteria were: (1) nonrandomized studies; (2) bare mental stents implantation; (3) studies with duplicate publication, or different follow-up periods from the same sample origin.

Data extraction and quality assessment

Two investigators (GXF and WZM) reviewed all selected articles independently to assess the eligibility of each article with standardized data-abstraction forms, and discrepancies were resolved by a third investigator (WF). The following data were extracted from the included studies: study design, baseline demographics, angiographic and procedural characteristics, and clinical outcomes at follow-up. The Cochrane tool was used to assess the qualities of the retrieved studies.

Study endpoints

The primary endpoint was the risk of MACE, as defined in each study. Other clinical endpoints included cardiac death, all cause death, myocardial infarction, target lesion revascularization (TLR), TVR and definite/probable stent thrombosis (according to the Academic Research Consortium criteria [21]). The definitions of each endpoint varied slightly across studies, and we used the study-specific definitions.

Statistical analysis

This meta-analysis was performed based on the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statements (Supplemental Table 1) [22]. Dichotomous variables are expressed as relative risks (RR) and 95% confidence interval (CI). The heterogeneity among trials was evaluated with Cochrane's Q test and I^2 statistic. When the p-value was <0.10 of Q test and/or I^2 was $\geq 50\%$, high heterogeneity was considered, and a random-effects model was selected. If not, the fixed-effects model with the Mantel–Haenszel method was performed. Publication bias of the included studies was estimated by Egger's test ($p<0.1$ for significant asymmetry) and funnel plots [23]. Treatment effects were also explored through sensitivity analysis and meta-regression. Moreover, subgroup analysis was performed to assess the benefit of IVUS-defined optimal procedure over suboptimal procedure. A two-tailed p value less than 0.05 was considered statistically significant. All analyses were conducted using STATA software 14.0 (Stata Crop., College Station, TX, USA).

Results

Eligible studies and patient characteristics

Nine eligible studies [9–14, 18, 24, 25], including a total of 4,724 patients, were identified in the present meta-analysis, with 2,359 patients in the IVUS guidance group and

2,365 in the angiography guidance group (Supplemental Fig. 1). The quality assessment using the Cochrane tool was listed in Supplemental Table 2. In general, the bias of all studies, except Tan et al. [13] and Zhang et al. [25], was low.

The detailed study design, clinical baseline, and procedural characteristics are presented in Tables 1, 2 and 3. Six studies [9–12, 14, 18] were conducted in multiple centers, and the remaining studies were three single-center studies [13, 24, 25]. Two studies [10, 12] enrolled patients with long coronary lesions. Two studies [11, 14] enrolled patients with CTO. One study [25] enrolled patients with small vessel disease. One study [13] enrolled patients with unprotected left main disease. The durations of dual antiplatelet therapy after PCI varied from 3 to 12 months, and clinical follow-up periods ranged from 12 to 24 months. The optimal criteria of IVUS guidance were slightly different and summarized in Supplemental Table 3.

MACE

All included studies reported MACE rates. As shown in Fig. 1, IVUS guidance has a lower risk of MACE compared with angiography guidance for DES implantation (5.4% vs. 9.0%; RR: 0.61, 95% CI 0.49–0.74, $p < 0.001$) without significant heterogeneity among studies ($p = 0.53$, $I^2 = 0\%$). No publication bias was found for MACE (Egger's test: $p = 0.21$; Supplemental Fig. 2A).

The sensitivity analyses indicated that omission of a single study from the overall analysis had no significant effect on the pooled results of MACE (Supplemental Fig. 3). We also performed the further sensitivity analyses: (1) removal two potentially high-bias studies by Tan et al. [13] and Zhang et al. [25] (RR: 0.63, 95% CI 0.51–0.78, $p < 0.001$; $I^2 = 0\%$, $p = 0.49$); (2) excluding studies with first generation DES (RR: 0.51, 95% CI 0.37–0.70, $p < 0.001$; $I^2 = 0\%$, $p = 0.85$); (3) limited to single-center studies (RR: 0.58, 95% CI 0.36–0.95, $p = 0.03$; $I^2 = 15.5\%$, $p = 0.31$) or multicenter studies (RR: 0.61, 95% CI 0.49–0.77, $p < 0.001$; $I^2 = 0\%$, $p = 0.53$); (4) limited to studies with 12-month follow-up (RR: 0.50, 95% CI 0.37–0.67, $p < 0.001$; $I^2 = 0\%$, $p = 0.87$) or 24-month follow-up (RR: 0.72, 95% CI 0.53–0.98, $p = 0.04$; $I^2 = 0\%$, $p = 0.43$). Notably, subgroup analysis [10, 18] demonstrated that patients who met the optimal criteria had a lower rate of MACE than those with IVUS-defined suboptimal procedure (RR 0.33, 95% CI 0.06–0.60, $p = 0.02$; $I^2 = 2\%$, $p = 0.88$; Fig. 2). Moreover, meta-regression analysis showed that the beneficial effect of IVUS guidance over angiography guidance still existed and were not influenced by acute coronary syndrome ($p = 0.63$), diabetes ($p = 0.59$), lesion length ($p = 0.66$) and follow-up duration ($p = 0.45$).

Other clinical outcomes

Eight studies [9–14, 18, 25] reported cardiac death rates. IVUS guidance was associated with a significant reduced risk of cardiac death (0.6% vs. 1.2%; RR: 0.49, 95% CI 0.26–0.92, $p = 0.03$; Fig. 3a) compared with angiography guidance, and no significant heterogeneity or publication bias was found ($I^2 = 0\%$, $p = 0.99$; Egger's test: $p = 0.64$; Supplemental Fig. 2B). No significant differences in the risk of all cause death (1.7% vs. 2.2%; RR: 0.78, 95% CI 0.46–1.31, $p = 0.34$; $I^2 = 0\%$, $p = 0.80$; Fig. 3b) and myocardial infarction (1.7% vs. 2.2%; RR: 0.79, 95% CI 0.54–1.17, $p = 0.24$; $I^2 = 0\%$, $p = 0.63$; Fig. 3c) were noted between IVUS guidance and angiography guidance with potential publication bias (Egger's test: $p = 0.07$ and $p = 0.01$; Supplemental Fig. 2C, D). In addition, six studies [9, 11, 12, 14, 18, 25] reported TVR data, and 7 studies [9–11, 13, 14, 18, 24] provided TLR rates. IVUS guidance was associated with a significant lower incidence of TVR than angiography guidance (3.5% vs. 6.1%; RR 0.58, 95% CI 0.42–0.80, $p = 0.001$; $I^2 = 0\%$, $p = 0.93$; Fig. 3d) as well as TLR (3.1% vs. 5.2%; RR 0.59, 95% CI 0.44–0.80, $p = 0.001$; $I^2 = 0\%$, $p = 0.87$; Fig. 3e). No publication biases of TVR and TLR were found (Egger's test: $p = 0.15$ and $p = 0.57$; Supplemental Fig. 2E, F. IVUS guidance was also related to a low risk of definite/probable stent thrombosis (0.5% vs .1.1%; RR 0.45, 95% CI 0.23–0.87, $p = 0.02$; Fig. 3F). No heterogeneity ($I^2 = 0\%$, $p = 0.66$) and publication bias (Egger's test: $p = 0.47$; Supplemental Fig. 2G) were found.

Discussion

The present meta-analysis with the largest sample size to date, including the latest ULTIMATE trial, demonstrated that (1) IVUS guidance was associated with significant lower risks of MACE, cardiac death, TVR, TLR, and definite/probable stent thrombosis at a mean follow-up of 16.7 months compared with angiography guidance; (2) no significant differences in all cause death and myocardial infarction were noted between IVUS guidance and angiography guidance; (3) subgroup analysis showed that patients who met the optimal criteria had a lower rate of MACE than those undergoing an IVUS-defined suboptimal procedure.

Coronary angiography is considered a gold standard for evaluating coronary lesions over the past several decades. However, the major limitation of coronary angiography is that it could not assess coronary anatomy accurately because coronary angiography only produces two-dimensional images of three-dimensional coronary lumen.With

Table 1 Study design of the included study

	Year	Sample size (n)	Center	Key inclusion criteria	DES type	FU (mo)	Primary endpoint	MACE
HOME DES IVUS	2010	105/105	Single center	AHA defined lesion type B2/C, proximal LAD, LM, RVD < 2.5 mm, lesion length > 20 mm, ISR, insulin dependent DM and ACS	First generation	18	MACE	Death, MI, TLR
AVIO	2013	142/142	Multicenter	Long lesions (> 28 mm), CTO, bifurcation lesions, small vessels (≤ 2.5 mm), patients requiring 4 or more stents	First generation	24	Post-PCI MLD	Cardiac death, MI, or TVR
RESET	2013	269/274	Multicenter	De novo lesion requiring a stent length ≥ 28 mm (RVD ≥ 2.5 mm)	Second generation	12	MACE	Cardiac death, MI, TVR or ST
AIR-CTO	2015	115/115	Multicenter	CTO	First/second generation	24	In-stent late lumen loss	Death, MI TLR, ST
CTO-IVUS	2015	201/201	Multicenter	CTO	Second generation	12	Cardiac death	Cardiac death MI, or TVR
Tan et al.	2015	61/62	Single center	Unprotected LM	First generation	24	MACE	Cardiac death MI, or TLR
IVUS-XPL	2015	700/700	Multicenter	Long lesions requiring stent length ≥ 28 mm(RVD 2.5–4 mm)	Second generation	12	MACE	Cardiac death, target lesion MI, or TLR
Zhang et al.	2016	42/42	Single center	De novo lesion in a small vessel (diameter 2.25–2.75 mm)	NR	12	Post-PCI MLD	Cardiac death MI, or TVR
ULTIMATE	2018	724/724	Multicenter	All comers	Second generation	12	TVF (cardiac death, TVMI or TVR)	Cardiac death, TVMI or TVR

AHA American Heart Association, *ACS* acute coronary syndrome, *CTO* chronic total occlusion, *DES* drug-eluting stent, *DM* diabetes mellitus, *FU* follow-up, *ISR* in-stent restenosis, *LAD* left anterior descending artery, *LM* left main disease, *MACE* major adverse cardiac events, *MI* myocardial infarction, *MLD* minimum lumen diameter, *NR* not reported, *RVD* reference vessel diameter, *ST* stent thrombosis, *TVF* target vessel failure, *TVMI* target vessel myocardial infarction, *TVR* target vessel revascularization

Table 2 Baseline clinical characteristics of the included studies

	Age (years)	Male (%)	Hypertension (%)	Dyslipidemia (%)	DM (%)	Current smoker (%)	Previous MI (%)	ACS (%)	LVEF (%)
HOME DES IVUS	59/60	73/71	67/71	63/66	42/45	40/35	37/32	72/60	NR
AVIO	64/64	82/77	70/67	70/77	24/27	35/31	NR	30/26	55/56
RESET	63/64	66/55	61/66	61/62	32/30	22/17	1/3	47/49	NR
AIR-CTO	67/66	89/80	75/70	22/28	30/27	39/39	21/30	29/24	55/56
CTO-IVUS	61/61	81/81	63/64	NR	35/34	35/34	8/8	NR	57/57
Tan et al.	77/76	62/69	41/47	NR	34/30	44/47	16/21	70/66	55/53
IVUS-XPL	64/64	69/69	65/63	67/65	36/37	22/26	5/4	49/49	63/62
Zhang et al.	63/60	50/60	64/60	48/60	NR	52/52	NR	NR	58/57
ULTIMATE	65/66	74/73	71/72	54/55	30/31	35/32	9/12	79/78	61/60

Data are presented as intravascular ultrasound guidance/angiography guidance

ACS Acute coronary syndrome, *DM* diabetes, *LVEF* left ventricular ejection fraction, *MI* myocardial infarction, *NR* not reported

Table 3 Angiographic and procedural characteristics of the included studies

	HOME DES IVUS	AVIO	RESET	AIR-CTO	CTO-IVUS	Tan et al.	IVUS-XPL	Zhang et al.	ULTIMATE
Lesion specificities (%)									
LM	3/4	NR	0/0	0/3	0/0	100/100	0/0	0/0	10/9
LAD	56/54	53/49	50/58	44/37	42/47	NR	65/60	48/52	48/47
LCX	11/15	NR	21/18	21/15	14/16	NR	14/15	49/51	17/17
RCA	29/24	NR	29/24	35/46	44/37	NR	21/25	56/44	25/28
Multi-vessel disease (%)	60/54	NR	41/38	49/57	72/63	66/63	67/70	NR	53/57
Post-dilation (%)	24/0	88/68	48/43	NR	51/41	23/9	76/57	NR	97/95
Stent number	1.3/1.3	NR	NR	1.6/1.5	1.7/1.6	NR	1.3/1.3	NR	1.8/1.8
Stent diameter (mm)	NR	3.0/2.9	NR	3.1/2.9	2.9/2.9	3.4/3.4	NR	2.6/2.5	3.1/3.0
Stent length (mm)	23.6/22.1	23.9/23.2	30/30	55/52	43.6/41.5	21.5/18.2	39.3/39.2	26.1/23.3	50.0/47.4
Max balloon diameter (mm)	3.3/3.1	3.4/3.2	NR	NR	NR	NR	3.1/3.0	2.9/2.6	3.7/3.5
Max post-dilation pressure (atm)	16.4/15.2	20.3/19.6	13.4/13.5	NR	14.6/13.8	NR	16.5/15.9	15.9/14.1	19.7/19.0
Contrast volume (ml)	133/113	NR	NR	293/293	299/295	NR	NR	NR	178/162
Lesion length (mm)	18.1/17.6	27.4/25.5	25.2/26.1	29.0/30.6	36.3/35.5	NR	34.7/35.2	17.0/15.1	35.1/34.1
Reference vessel diameter (mm)	3.2/3.0	2.7/2.6	2.9/2.8	2.7/2.6	2.7/2.6	NR	2.9/2.9	2.4/2.4	2.7/2.8
Pre-procedural MLD (mm)	1.1/1.0	0.8/0.7	1.0/1.0	NR	NR	1.9/1.9	0.8/0.8	0.9/0.90	0.9/0.9
Pre-procedural DS (%)	82.3/79.2	71.6/75.5	NR	100/100	100/100	NR	71.1/71.4	77.8/77.8	68.1/66.1
Post-procedural MLD (mm)	2.9/2.9	2.6/2.4	2.6/2.6	2.6/2.4	2.6/2.6	3.4/3.4	2.6/2.6	2.8/2.5	2.5/2.5
Post-procedural DS (%)	14.6/15.3	13.9/15.5	NR	11.0/13.8	9.0/10.2	NR	12.8/13.7	6.7/7.9	12.2/12.0

Data are presented as intravascular ultrasound guidance/angiography guidance

CTO Chronic total occlusion, *DS* diameter stenosis, *LAD* left anterior descending artery, *LCX* left circumflex artery, *LM* left main, *MLD* minimum luminal diameter, *NR* not reported, *RCA* right coronary artery

a high spatial resolution, IVUS overcomes several limitations of coronary angiography by providing more accurate information about vessel wall and lesion severity. In addition, IVUS is also helpful to select the optimal stent and balloon size and increase the additional use of postdilation with larger balloons and at higher pressures,

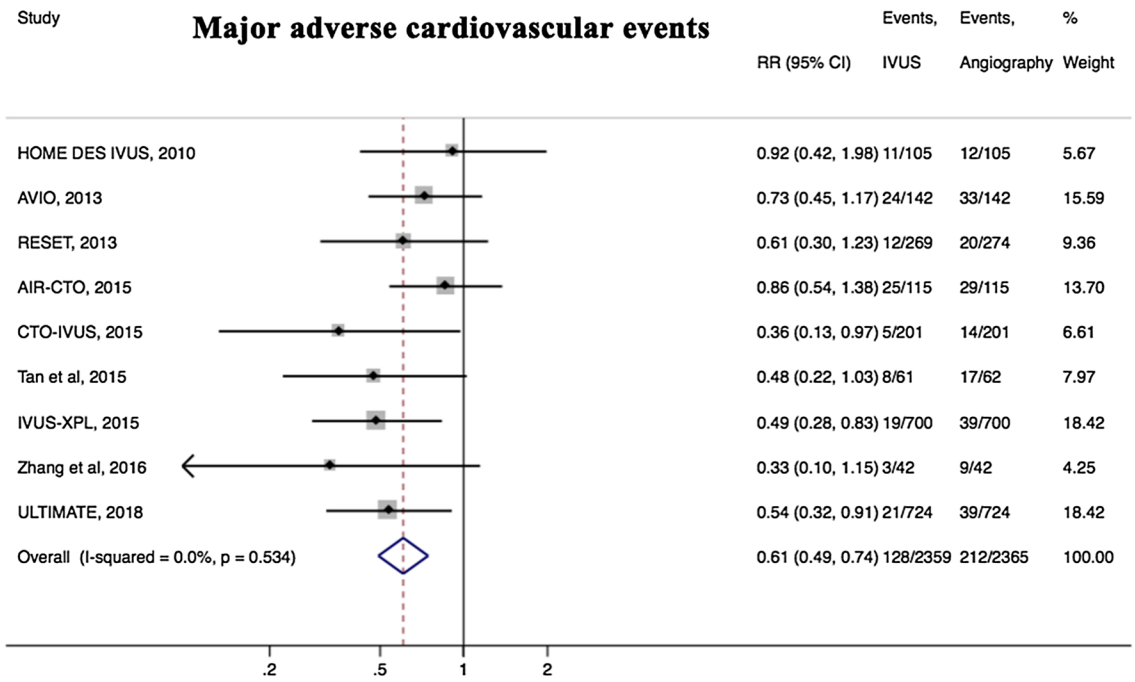

Fig. 1 Forest plots for major adverse cardiovascular events. Relative risk of major adverse cardiovascular events (MACE) associated with intravascular ultrasound (IVUS)-guided compared with angiography-guided drug-eluting stent (DES) implantation

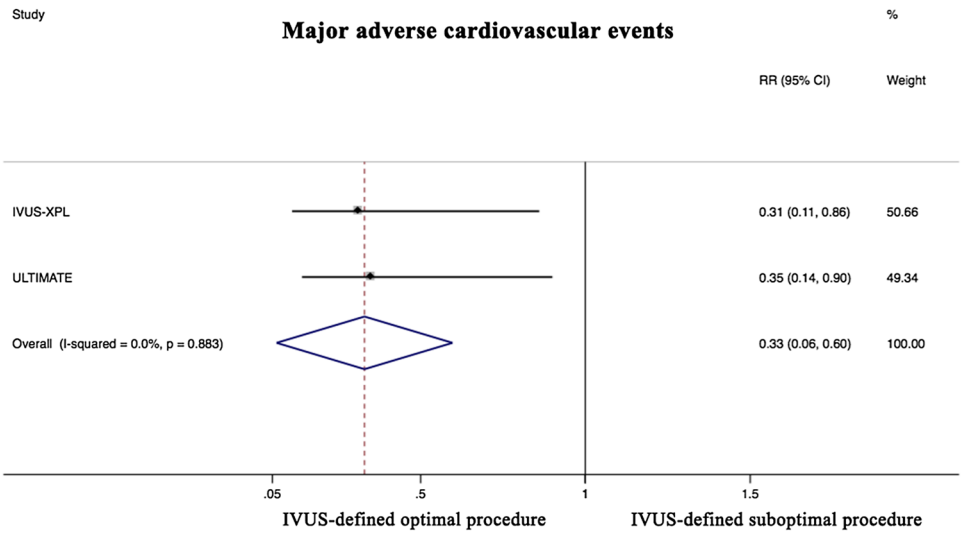

Fig. 2 Forest plot for major adverse cardiovascular events associated with intravascular ultrasound (IVUS)-defined optimal procedure compared with suboptimal procedure

resulting in larger postprocedural MLD, whichis potentially associated with the improved clinical outcomes of PCI.

In the BMS era, IVUS-guided BMS implantation was associated with reductions in restenosis and TVR without significant benefit in mortality or MI. The meta-analysis [1], including 7 randomized trials, demonstrated that IVUS-guided BMS implantation improved the acute procedural results (MLD) and thereby reduced restenosis and repeat revascularization with a neutral effect on death and myocardial infarction during a follow-up period of 6 months to 2.5 years.

Given the encouraging results of IVUS guidance in the BMS era and the advantage of DES [2], IVUS-guided DES implantation is widely accepted in complex lesion and high-risk patient subsets. Of note, the risks of stent underexpansion, stent malapposition, and stent edge dissections appear high in patients with complex lesions, which consequently lead to adverse events. IVUS guidance has a beneficial effect on optimizing stent apposition and results in larger

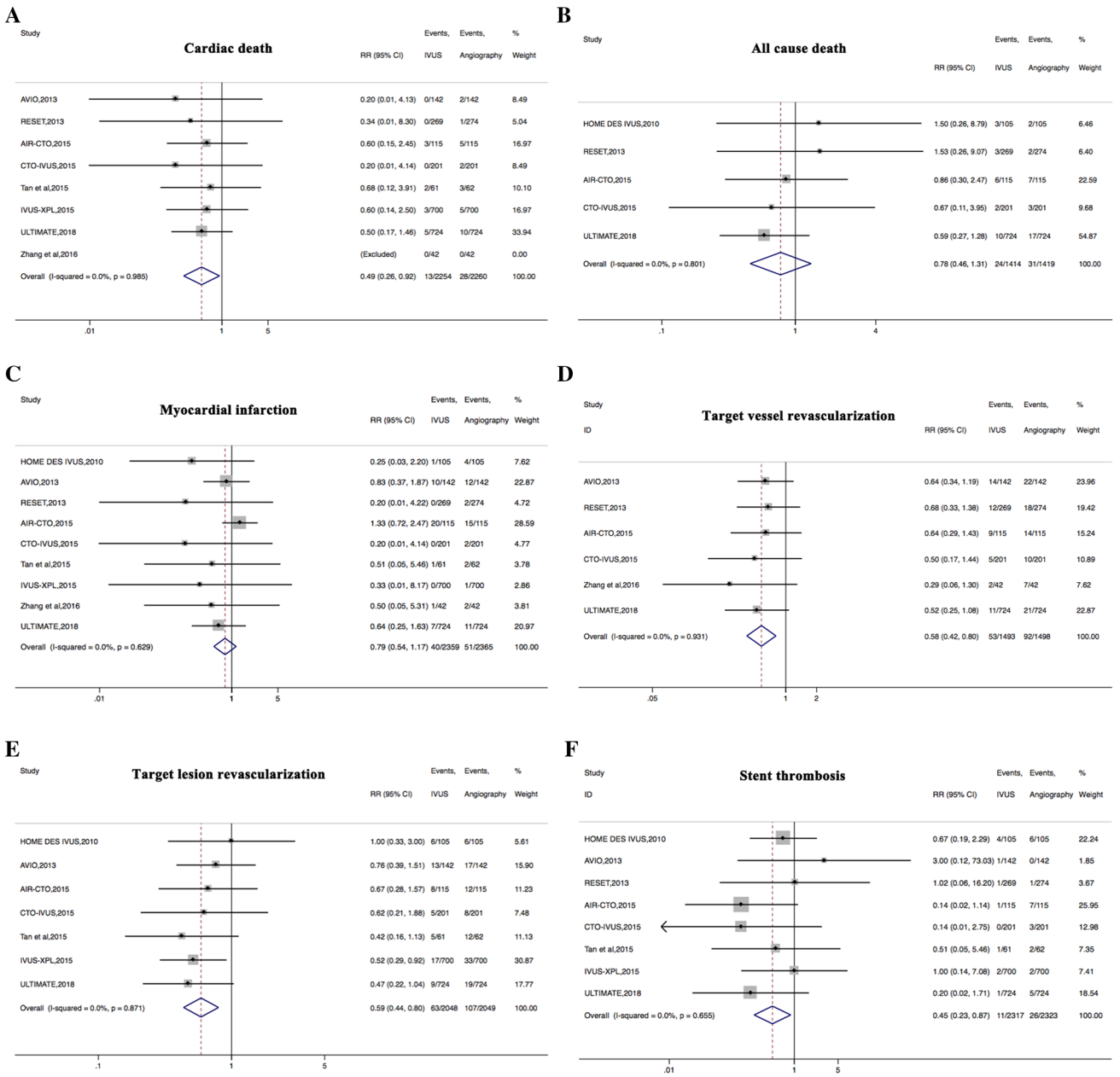

Fig. 3 Forest plots for other clinical outcomes. Relative risks of cardiac death (**a**), all cause death (**b**), myocardial infarction (**c**), target vessel revascularization (TVR) (**d**), target lesion revascularization (TLR) (**e**), and definite/probable stent thrombosis (**f**) associated with intravascular ultrasound (IVUS)-guided compared with angiography-guided drug-eluting stent (DES) implantation

MLD, which were thought to be more useful for the complex lesions. Indeed, several RCTs [9–12, 14] and meta-analyses [3, 15–17, 19] have confirmed that IVUS-guided DES implantation is associated with better clinical outcomes in complex lesion subsets (long lesions, bifurcation lesions, chronic total occlusion, and unprotected left main disease). Overall, the benefit of IVUS guidance is evident in patients with acute coronary syndromes and complex lesions.

However, routine use of IVUS in guiding DES implantation was controversial until the ULTIMATE trial [18] showed the superiority of IVUS guidance over angiography. The American National Cardiovascular Data Registry [26] showed that IVUS was used in 20.3% of total cases, while 73.6% patients had lesions assessed by angiography only. The potential explanation of this phenomenon is that a number of operators might think that angiographic assessment only is sufficient for a majority of coronary lesions, especially at the cost of increased procedural time and expense. Indeed, several observational studies [27, 28] had conflicting results regarding the routine use of IVUS, which

might be due to the study design, especially the low rate of optimal stent deployment in the IVUS guidance group. The ULTIMATE trial [18], which is the largest RCT in the IVUS guidance field, including 1,448 all-comer patients who required DES implantation, showed that IVUS guidance could reduce the 12-month TVF by 47% compared with angiography guidance in all-comers. Hence, ULTIMATE trial has provided evidence to address the role of IVUS guidance in all-comer patients with DES implantation, which also contribute to the significant reduction of cardiac death and stent thrombosis in this meta-analysis with the largest sample size to date in contrast to previous studies [3, 15].

The benefit of IVUS guidance over angiography guidance in both complex lesions and simple lesions has been well established according to previous data and the present meta-analysis. Next, we should focus on how many procedural strategies are changed by IVUS guidance, which could reflect the real value of IVUS guidance, rather than only IVUS use during PCI. Notably, the optimal IVUS criteria of DES implantation were slightly different in previous studies [9–11, 13, 14, 18]. The IVUS-defined criteria for the optimal stent deployment in ULTIMATE trial [18] included the following: (1) MLA in stented segment > 5.0 mm^2 or 90% of the MLA at the distal reference segments; (2) plaque burden at the 5 mm proximal or distal to the stent edge less than 50%; (3) no edge dissection involving media with length longer than 3 mm. At 12 months after PCI, patients who met all three optimal criteria had a lower risk of TVF compared with that in patients with IVUS-defined suboptimal procedure (1.6% vs. 4.4%, p = 0.03). Therefore, optimal IVUS-defined DES implantation could provide more benefit thanexclusive IVUS use during PCI. The further RCTs are needed to explore the most optimal criteria of IVUS guidance and how to achieve these IVUS criteria.

Limitations

Our study has several limitations. First, the present meta-analysis is not based on individual patient data, so we could not perform more subgroup analyses. Second, clinical and procedural characteristics, crossover rate, optimal IVUS criteria, and follow-up duration were slightly different among trials. However, the heterogeneity was quite low according to Cochrane's Q test and I^2 statistic, and sensitivity analyses and meta-regression analyses were also performed to elucidate the relationship between these confounding factors and IVUS guidance. Third, the definitions of MACE varied slightly across these studies, but there is a very clear benefit of IVUS guidance regarding cardiac death, TLR and TVR. Finally, the follow-up duration in all enrolled studies was relatively different, and longer follow-up is required for comparison of IVUS guidance and angiography guidance.

Conclusions

The present meta-analysis, including 9 RCTs and 4724 patients, demonstrates that IVUS-guided DES implantation is associated with a significant lower risk of MACE, cardiac death, TVR, TLR, and stent thrombosis, especially for patients with IVUS-defined optimal procedure, compared with angiography guidance.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to declare.

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