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Transcatheter Aortic Valve Implantation With or Without Percutaneous Coronary Artery Revascularization Strategy: A Systematic Review and Meta-Analysis

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***Background*—**Recent recommendations suggest that in patients with severe aortic stenosis undergoing transcatheter aortic valve implantation and coexistent significant coronary artery disease, the latter should be treated before the index procedure; however, the evidence basis for such an approach remains limited. We performed a systematic review and meta-analysis to study the clinical outcomes of patients with coronary artery disease who did or did not undergo revascularization prior to transcatheter aortic valve implantation.

***Methods and Results*—**We conducted a search of Medline and Embase to identify studies evaluating patients who underwent transcatheter aortic valve implantation with or without percutaneous coronary intervention. Random-effects meta-analyses with the inverse variance method were used to estimate the rate and risk of adverse outcomes. Nine studies involving 3858 participants were included in the meta-analysis. Patients who underwent revascularization with percutaneous coronary intervention had a higher rate of major vascular complications (odd ratio [OR]: 1.86; 95% confidence interval [CI], 1.33–2.60; *P*=0.0003) and higher 30-day mortality (OR: 1.42; 95% CI, 1.08–1.87; *P*=0.01). There were no differences in effect estimates for 30-day cardiovascular mortality (OR: 1.03; 95% CI, 0.35–2.99), myocardial infarction (OR: 0.86; 95% CI, 0.14–5.28), acute kidney injury (OR: 0.89; 95% CI, 0.42–1.88), stroke (OR: 1.07; 95% CI, 0.38–2.97), or 1-year mortality (OR: 1.05; 95% CI, 0.71–1.56). The timing of percutaneous coronary intervention (same setting versus a priori) did not negatively influence outcomes.

***Conclusions*—**Our analysis suggests that revascularization before transcatheter aortic valve implantation confers no clinical advantage with respect to several patient-important clinical outcomes and may be associated with an increased risk of major vascular complications and 30-day mortality. In the absence of definitive evidence, careful evaluation of patients on an individual basis is of paramount importance to identify patients who might benefit from elective revascularization. **(*J Am Heart Assoc*. 2017;6:e005960. DOI: 10.1161/JAHA.117.005960.)**

Key Words: coronary artery disease • percutaneous coronary intervention • transcatheter aortic valve implantation

Coronary artery disease (CAD) often coexists in patients with severe aortic stenosis (AS),[1,2] and current American and European guidelines recommend combined coronary artery bypass grafting at the time of surgical aortic valve replacement.[3,4] Concomitant coronary artery bypass grafting and surgical aortic valve replacement are

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Received February 24, 2017; accepted May 3, 2017.

Clinical Perspective

What Is New?

- The prevalence of coexisting coronary artery disease in populations undergoing transcatheter aortic valve implantation averaged 70%.
- Anatomically significant coronary artery disease was inconsistently defined and varied from at least ≥50% to >90% diameter stenosis.
- None of the available data reported on the use of functional assessment for coronary artery disease significance.
- Major vascular complications and 30-day mortality may be increased among patients undergoing percutaneous coronary intervention revascularization before transcatheter aortic valve implantation procedures.
- No significant benefit was observed with percutaneous coronary intervention revascularization in terms of 1-year mortality.
- The timing, a priori versus concomitant percutaneous coronary intervention revascularization strategies, showed comparable results.

What Are the Clinical Implications?

- Routine revascularization before or during transcatheter aortic valve implantation confers no clinical advantage with respect to several patient-important clinical outcomes.
- In the absence of definitive evidence, careful evaluation of patients by a dedicated heart team is of paramount importance to identify patients for whom the benefits of elective revascularization are balanced against the potential risks.
- Randomized controlled trials are needed to determine the role of routine revascularization in patients with significant coronary artery disease undergoing transcatheter aortic valve implantation.

associated with worse postoperative outcomes, although with no negative impact on operative and 1-year mortality.[5,6] Nevertheless, the role of revascularization in long-term morbidity and mortality in octogenarians is still not clear.[7]

The prevalence of CAD in the population undergoing transcatheter aortic valve implantation (TAVI) is higher than that in those undergoing surgical aortic valve replacement, and depending on the definition, the presence of significant CAD ranges from 50% to 75%.[8–12] Notably, randomized clinical trials that led to the approval of TAVI devices in United States required revascularization of significant CAD affecting main epicardial vessels within 30 days of TAVI. In this context, it has been recommended to perform percutaneous coronary intervention (PCI) or a hybrid procedure to revascularize patients with significant CAD.[13–15] Favorable outcomes associated with prior-TAVI PCI have been reported in single-center studies with relatively small sample sizes, although these were often underpowered for the end points studied and were subject to significant selection biases. In addition, data on whether revascularization should be performed before or in the same setting are still scant. The aim of this report was to perform a systematic review and meta-analysis to assess the evidence basis and clinical outcomes associated with TAVI procedures performed with and without revascularization of coexistent CAD with PCI.

Methods

Search Strategy

We conducted a search of Medline, Embase, Google Scholar, Science Direct, Web of Science, and conference abstracts from conception to September 2016 using OvidSP. One study published after the systematic search was updated from its previous publication in a conference abstract format and then included in the qualitative synthesis. The following terms were used: *(transcatheter aortic valve implantation OR transfemoral aortic valve implantation OR transapical aortic valve implantation OR trans-subclavian aortic valve implantation OR TAVI OR transcatheter aortic valve replacement OR TAVR) AND (percutaneous coronary intervention OR PCI OR coronary angioplasty)*. Institutional review board approval and patient consent were not required because of the nature of this study as a systematic review and meta-analysis.

Study Selection

The abstract and titles yielded by the search were screened by 2 independent investigators (R.A.K. and C.S.K.) against the inclusion criteria. Additional studies were retrieved by checking the bibliography of included studies and relevant reviews. The full reports of potentially relevant studies were retrieved, and data were independently extracted on study design, participant characteristics, treatment groups, outcome events, follow-up, and results. Any discrepancies between reviewers were resolved by discussion after consulting a third investigator (R.B.).

Eligibility Criteria

We included only studies published in English that evaluated patients with underlying CAD who underwent PCI as a revascularization strategy prior to or concomitantly with TAVI versus no revascularization. In terms of outcomes, studies included must have evaluated ≥1 of the following

events: 30-day and 1-year mortality, myocardial infarction (MI), vascular complications, bleeding, neurological events (stroke or transient ischemic attack), or acute kidney injury (AKI). End points were reported, when available, in accordance to Valve Academic Research Consortium 2 definitions.[16] The reporting of outcomes had to include either crude events in each group or any risk or odds estimate (risk ratio or odds ratio [OR]) with 95% confidence intervals (CIs). There was no restriction based on the design of the study or the duration of follow-up. We excluded isolated case reports or case series (≤3 patients), reviews, and editorial comments on the subject. When duplicate reports of the same study were identified, only the report with the most complete data set and detailed methodology description was included. A flow diagram is provided following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses[17]; Figure 1).

Quality and Risk of Bias Assessment

To assess the quality of included cohort studies, we used the Newcastle-Ottawa Scale.[18] The outcomes of interest and follow-up were also extracted on a preformatted table. Disagreements were resolved by consensus after consultation with an investigator (R.B.). Risk of bias was assessed by considering the ascertainment of treatment groups, the ascertainment of outcomes, loss to follow-up, and potential confounders in the data analysis.

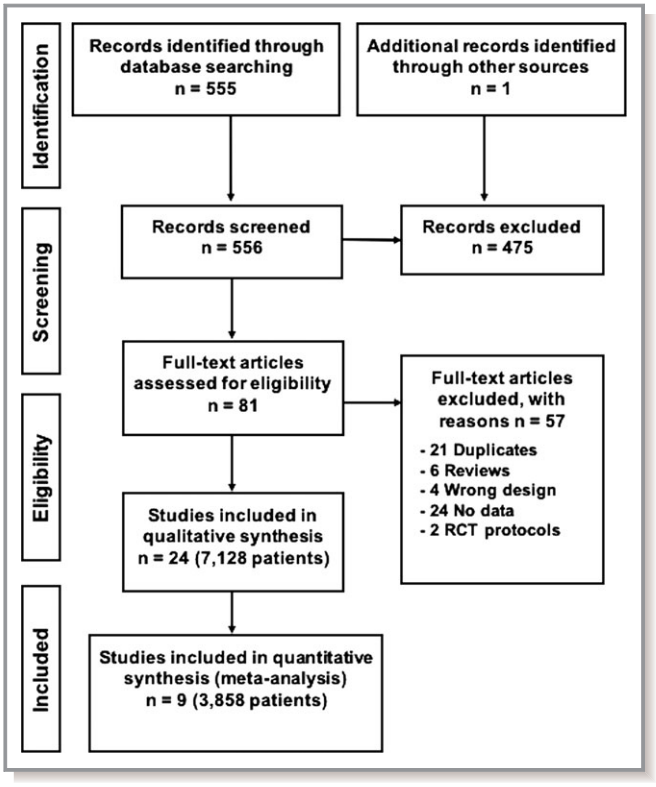

Figure 1. Flow diagram based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses).

Data Analysis

We used RevMan (Review Manager version 5.1.7, Nordic Cochrane Centre, Denmark) to perform random-effects meta-analysis using the Mantel-Haenszel method to determine pooled ORs for dichotomous data with regard to post-TAVI outcomes with and without PCI revascularization. To ensure a meta-analysis with clinically transferable results, we included only studies in which the methodology or data set permitted adjudication of CAD prevalence in the TAVI-alone group. The Cochrane Q statistic (I^2) was used to assess the consistency among studies, with I^2<25% considered low, I^2 values of 25% to 50% considered moderate, and I^2>75% considered high statistical heterogeneity.[19] If there were insufficient data or studies for meta-analysis, we pooled the studies using weighted average or performed narrative synthesis of studies that were too heterogeneous to pool. Sensitivity analyses were performed to assess the potential influence of any estimates on treatment effect or association that were derived from the mean by excluding a study considered as an outlier.[20] In addition, sensitivity analyses further assessed for potential differences between random- and fixed-effects models, excluding studies in which one of the treatment arms had no events. Subgroup analyses were performed to determine whether treatment effect was influenced by studies reporting a population with 100% versus >50% (but <100%) of the patients presenting with CAD. Meta-regression was performed to further investigate the potential source of clinical heterogeneity[21] and to determine the influence of CAD on outcomes. The *metareg* function (STATA 14.0) was used to undertake metaregression with log-risk estimates and the standard error determined from 95% CIs for the log-risk estimates. Prevalence of CAD was calculated by averaging the percentage of patients with CAD in TAVI-PCI and TAVI-alone groups. Two-sided *P* values of <0.05 were considered statistically significant.

Results

Study Population

A total of 24 observational studies[9–12,22–41] including 7128 participants met the inclusion criteria for the systematic review; among these, 9 studies* met criteria for the meta-analysis, evaluating 3858 participants (Figure 1) of which 983

*References 9, 10, 12, 25, 31, 32, 35, 37, 40.

underwent TAVI with PCI revascularization strategy. The mean age was 85.3 years and 48.4% were female in 14 studies that reported both age and gender.[†] Anatomically significant CAD was inconsistently defined and included at least ≥50% diameter stenosis in 7 studies,[9,10,12,28,29,34,38] >70% stenosis in 5 studies,[11,24,31,36,37] and >90% stenosis in 1 study.[35] A total of 4 studies[11,35,37,38] defined >50% stenosis when located in the left main. None of the studies reported on the use of functional assessment for CAD significance. Further details on study design and participants baseline characteristics are presented in Tables 1 and 2.

Quality Assessment

Ascertainment of outcomes varied from medical record reviews to prospective evaluation with adjudicated clinical end points. All studies contained no major loss to follow-up, and the overall quality level was average. Follow-up of patients varied from in-hospital outcomes, clinical visits, and telephone calls up to 4 years from the date of implant. Although follow-up among studies was inconsistent, the most common time points were at 30 days and 1 year. The Newcastle-Ottawa quality assessment is presented in Table 3.

In-Hospital, 30-Day, and Long-Term Outcome With PCI Versus TAVI Alone

Device type, access site, procedure-related outcomes, and follow-up assessment for all included studies reporting crude rate of events are summarized in Table 4. Crude outcomes for strategies with versus without revascularization (PCI) are shown in Table 5. Crude all-cause 30-day mortality was reported in 18 studies[‡] and occurred in 6.97% (368/5281) of patients; crude cardiovascular 30-day mortality was reported in 5 studies[10,12,28,31,32] and occurred in 5.0% (52/1046) of patients. At 30 days, the crude incidence of MI was reported in 9 studies[10–12,28,31–33,35,39] and occurred in 0.8% (26/3109) of patients, major or life-threatening bleeding was reported in 12 studies[10–12,28,31–34,36,39–41] and occurred in 14.5% (590/4074) of patients, and AKI was reported in 13 studies[§] and occurred in 6.04% (259/4288) of patients.

Meta-analyses evaluating outcomes showed that patients who underwent revascularization were more likely to experience major vascular complications (OR: 1.86; 95% CI, 1.33–2.60; P=0.0003; heterogeneity: P=0.83, I^2=0%) and higher 30-day mortality (OR: 1.42; 95% CI, 1.08–1.87; P=0.01; heterogeneity: P=0.63, I^2=0%). There were no significant differences in effect estimates for 30-day cardiovascular mortality (OR: 1.03; 95% CI, 0.35–2.99), MI (OR: 0.86; 95% CI, 0.14–5.28), major or life threatening bleeding (OR: 0.82; 95% CI, 0.54–1.26), AKI and/or need for hemodialysis (OR: 0.89; 95% CI, 0.42–1.88), stroke or transient ischemic attack (OR: 1.07; 95% CI, 0.38–2.97), and the combined safety end point (OR: 0.81; 95% CI, 0.48–1.37; Figure 2).

A total of 9 studies reported 1-year mortality rates,[9,27,28,32,35,37–39,41] and 2 studies reported 2-year mortality rates.[32,35] The crude incidence of death was 21.3% (545/2554) of patients at 1 year and 57.5% (258/449) at 2 years. Meta-analyses evaluating 1-year mortality for pre-TAVI PCI versus TAVI without revascularization showed no significant differences in point estimate (OR: 1.05; 95% CI, 0.71–1.56; P=0.81; heterogeneity: P=0.64, I^2=0%; Figure 2).

Notably, although most of the included studies were small and reported neutral results, Singh et al[40] presented a large sample size and reported adverse outcomes with PCI. In addition, the 95% CIs of all the studies except that of Singh et al overlap 1 (Figure 2), and the 95% CIs of the overall effect estimate do not overlap 1. Consequently, sensitivity analysis excluding this study showed a decrease in the effect estimates for 30-day mortality (OR: 1.15; 95% CI, 0.69–1.92; P=0.59; heterogeneity: P=0.62, I^2=0%) and major vascular complications (OR: 1.38; 95% CI, 0.61–3.10; P=0.44; heterogeneity: P=0.90, I^2=0%), although widening the CIs in the latter. The remaining sensitivity-analyzed outcomes remained unchanged (Figure 3).

Preprocedural Versus Same-Setting Revascularization

Revascularization PCI was performed either concomitantly with TAVI or a priori in 12 studies.[‖] Eight studies exclusively revascularized patients prior to TAVI,[9,12,24,28,31,36,37,41] 1 study did so in the same setting,[35] and 1 study reported both strategies.[10] Five studies reported outcomes based on PCI timing,[10,22,23,33,36] and those who underwent prior PCI varied from same setting[12] to 6 months[41] prior to TAVI.

Meta-analyses evaluating a priori PCI versus concomitant revascularization strategies showed comparable effect estimates for 30-day mortality (OR: 1.28; 95% CI, 0.41–4.00), major or life threatening bleeding (OR: 0.42; 95% CI, 0.14–1.26), or major vascular complications (OR: 0.30; 95% CI, 0.04–1.98; Figure 4).

[†]References 9–12, 23, 26, 28, 31–33, 35, 36, 39, 40.
[‡]References 9–12, 23, 25, 26, 28, 31–37, 39–41.
[§]References 10, 12, 22, 23, 28, 31–36, 39, 40.

[‖]References 10, 11, 22, 23, 25, 27, 29, 33, 34, 38–40.

Table 1. Study Design and Participant Characteristics

Study	Design; Country; Y	No. of Participants; PCI+TAVI; TAVI Alone	Participant Inclusion Criteria and CAD Significance Definition
Masson et al 2010[9]	Retrospective cohort study; Canada; 2005–2007	104; 15; 89	Patients for TAVI with ≥50% diameter stenosis in at least 1 coronary artery and DMJS score
Conradi et al 2011[23]	Retrospective cohort study; Germany; 2008–2010	28; 28; 0	Patients for TAVI who underwent PCI
Gautier et al 2011[11]	Retrospective cohort study; France; 2006–2009	83; 11; 72	Patients for TAVI with ≥70% epicardial coronary artery stenosis or ≥50% stenosis of left main
Nowakowski et al 2011[22]	Cohort study; Australia; Unclear	70; 15; 55	Patients for TAVI with no information for determination of CAD significance
Wenaweser et al 2011[10]	Retrospective cohort study; Switzerland; 2007–2010	256; 59; 197	TAVI patient with >50% diameter stenosis in at least 1 coronary artery
Abdel-Wahab et al 2012[12]	Retrospective cohort study; Germany; 2007–2011	125; 55; 70	TAVI patients with ≥50% stenosis on angiography or previous cardiac event
Bensaid et al 2012[24]	Cohort study; France; Unclear	61; 23; 38	TAVI patients with >70% proximal vessel stenosis
Aktug et al 2013[25]	Cohort study; Germany; 2008–2012	338; 66; 272	Patients for TAVI with CAD defined as clinically significant
Arnold et al 2013[26]	Retrospective cohort study; Germany; Unclear	300; 73; 227	Patients for TAVI with CAD defined as clinically significant
Codner et al 2013[27]	Retrospective cohort study; Israel; 2008–2012	153; 36; 117	Patients for TAVI with CAD defined as clinically significant
Czerwinska-Jelonkiewicz et al 2013[30]	Retrospective cohort study; Poland; 2009–2011	83; 18; 65	Not reported
Gasparetto et al 2013[28]	Retrospective cohort study; Italy; Unclear	152; 39; 113	Patients for TAVI with ≥50% diameter stenosis of at least 1 epicardial coronary artery
Van Mieghem et al 2013[29]	Retrospective cohort study; Netherlands; 2005–2012	138; 39; 99	Patients for TAVI with >50% diameter stenosis in any coronary artery
Abramowitz et al 2014[31]	Retrospective cohort study; Israel; 2009–2012	144; 61; 83	TAVI patients with >70% stenosis in major epicardial coronary artery
Griese et al 2014[33]	Retrospective cohort study; Germany; 2009–2012	411; 65; 346	TAVI patients with CAD significance defined as per the institution's current local practice
Tatar et al 2014[32]	Retrospective cohort study; France; 2008–2013	141; 38; 103	Patients for TAVI but no information of determination of CAD significance
Khawaja et al 2015[37]	Retrospective cohort study; United Kingdom; 2008–2012	93; 25; 68	Patients for TAVI with epicardial coronary artery stenosis ≥70% or left main stem stenosis of ≥50%
Mancio et al 2015[34]	Retrospective cohort study; Portugal; 2007–2012	46; 13; 33	Patients for TAVI with ≥50% stenosis in coronary artery
Penkalla et al 2015[35]	Retrospective cohort study; Germany; 2008–2013	308; 76; 232	>50% stenosis in left main or >90% stenosis in LAD, LCx, and RCA
van Rosendael et al 2015[36]	Retrospective cohort study; Netherlands, Unclear	96; 96; 0	TAVI patients with ≥70% stenosis of a coronary artery of ≥1.5 mm
Snow et al 2015[38]	Retrospective cohort study; United Kingdom; 2007–2011	1339; 172; 1167	TAVI patients with >50% stenosis main, LAD, LCx, and RCA
Chakravarty et al 2016[39]	Retrospective cohort and matched study; International; 2007–2014	256 (cohort); 128; 128	Patients with left main PCI from a TAVI-left main registry and matched controls
Singh et al 2016[40]	Retrospective cohort study with propensity matching; United States of America; 2011–2013	2349; 588; 1761	TAVI patients with CAD according to ICD-9 coding
Paradis et al 2017[41]	Retrospective cohort study; North America; 2007–2012	377; 54; 323	Patients for TAVI with CAD defined as significant if >50% of vessel diameter

CAD indicates coronary artery disease; DMJS, Duke Myocardial Jeopardy score; ICD-9, *International Classification of Diseases, Ninth Revision*; LAD, left anterior descending; LCx, left coronary circumflex; PCI, percutaneous coronary intervention; RCA, right coronary artery; TAVI, transcatheter aortic valve implantation.

Table 2. Baseline Characteristics for Patients Who Underwent TAVI With and Without PCI

Study	Strategy	Mean Age (Y)	Male	Logistic EuroSCORE	STS Score	CAD	Multivessel Disease	LVEF	CKD	COPD	PVD
Masson et al 2010[9]	TAVI+PCI	85.7	10 (66.6)	24.5	9.5	15 (100)	N/A	45.0	0 (0)	N/A	3 (20.0)
	TAVI alone	84.4	60 (57.8)	31.05	9.7	104 (100)		58.4	93 (89.4)		42 (40.3)
Conradi et al 2011[23]	TAVI+PCI	80.1	13 (46.4)	26.8	9.3	28 (100)	19 (67.9)	45.6	8 (28.6)	7 (25.0)	11 (39.3)
	TAVI alone	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gautier et al 2011[11]	TAVI+PCI	74±15	9 (81.8)	25±11	N/A	11 (100)	7 (63.6)	48±13	N/A	N/A	N/A
	TAVI alone	N/A	N/A	N/A		N/A	N/A	N/A			
Nowakowski et al 2011[22]	TAVI+PCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TAVI alone										
Wenaweser et al 2011[10]	TAVI+PCI	83.6±4.8	29 (49.2)	26.8±16.3	7.6±6.2	59 (100)	N/A	51±12	N/A	N/A	16 (27.1)
	TAVI alone	81.7±6.5	83 (42.1)	24.2±14.4	6.1±4.5	108 (54.8)		51±15			48 (24.4)
Abdel-Wahab et al 2012[12]	TAVI+PCI	81±7.1	26 (47.0)	25.08±12.6	N/A	55 (100)	18 (32.7)	46.9±13.9	N/A	N/A	11 (20.0)
	TAVI alone	81±6.2	34 (48.5)	23.62±15.1		36 (51.4)	27 (38.6)	48.5±15.3			10 (14.2)
Bensaid et al 2012[24]	TAVI+PCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TAVI alone										
Aktug et al 2013[25]	TAVI+PCI	N/A	N/A	N/A	N/A	66 (100)	N/A	N/A	N/A	N/A	N/A
	TAVI alone					155 (57)					
Arnold et al 2013[26]	TAVI+PCI	82±6	39 (54)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TAVI alone	81±6	78 (44)								
Codner et al 2013[27]	TAVI+PCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TAVI alone										
Czerwinska-Jelonkiewicz et al 2013[30]	TAVI+PCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TAVI alone										
Gasparetto et al 2013[28]	TAVI+PCI	N/A	N/A	N/A	N/A	39 (100)	N/A	N/A	N/A	N/A	N/A
	TAVI alone	80.3±6.3	57 (50.4)	23.2±14.1		113 (100)		52.8±12.9	65 (57.5)	25 (22.1)	
Van Mieghem et al 2013[29]	TAVI+PCI	N/A	N/A	N/A	N/A	39 (100)	N/A	N/A	N/A	N/A	N/A
	TAVI alone					99 (100)					
Abramowitz et al 2014[31]	TAVI+PCI	83.6±5.5	33 (50.8)	31.3±13.8	N/A	61 (100)	35 (57.4)	54.6±9	N/A	7 (11.5)	10 (16.4)
	TAVI alone	83.1±5.1	40 (48.2)	29.2±13.8		83 (100)	47 (56.7)	55.2±7.5		21 (25.3)	14 (16.9)
Griese et al 2014[33]	TAVI+PCI	82±6	24 (36.9)	21.7±13.9	N/A	N/A	N/A	52±15	36 (55.3)	N/A	N/A
	TAVI alone	82±5	129 (37.3)	20.3±14.6				54±14	177 (51.2)		

Continued

DOI: 10.1161/JAHA.117.005960

Table 2. Continued

Study	Strategy	Mean Age (Y)	Male	Logistic EuroSCORE	STS Score	CAD	Multivessel Disease	LVEF	CKD	COPD	PVD
Tatar et al 2014[32]	TAVI+PCI	85±5	18 (47.4)	31.3±16.6	7.8±5.8	38 (100)	19 (50.0)	N/A	11 (29.0)	8 (21.1)	8 (21.1)
	TAVI alone	84±6	54 (52.0)	31.7±16.8	7.5±4.7	54 (52.4)	10 (9.7)		41 (39.8)	35 (34.0)	41 (39.8)
Khawaja et al 2015[37]	TAVI+PCI	N/A	N/A	N/A	N/A	25 (100)	N/A	N/A	N/A	N/A	N/A
	TAVI alone					68 (100)					
Mancio et al 2015[34]	TAVI+PCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TAVI alone										
Penkalla et al 2015[35]	TAVI+PCI	83 (78–86)	21 (27.6)	32.1 (19–52)	11.9 (7–19)	76 (100)	N/A	55 (40–60)	N/A	N/A	50 (65.8)
	TAVI alone	81 (76–85)	88 (37.9)	28.5 (18–45)	10.1 (6–19)	232 (100)		50 (41–60)			160 (69.0)
van Rosendael et al 2015[36]	TAVI+PCI	81±5.4	55 (57.3)	23.2±12.9	N/A	96 (100)	N/A	54±13	N/A	N/A	N/A
	TAVI alone	N/A	N/A	N/A		N/A		N/A			
Snow 2015[38]	TAVI+PCI	N/A	N/A	N/A	N/A	172 (100)	N/A	N/A	N/A	N/A	N/A
	TAVI alone					1167 (100)					
Chakravarty 2016[39]	TAVI+PCI	81.7±6.8	81 (63.3)	N/A	7.8±4.9	128 (100)	N/A	53.5±12.4	N/A	N/A	44 (34.4)
	TAVI alone	81.0±7.9	88 (68.7)		8.0±4.5	128 (100)		55.5±13.6			50 (41.4)
Singh et al 2016[40]	TAVI+PCI	83.0±0.59	279 (47.4)	N/A	N/A	493 (83.9)	N/A	N/A	N/A	164 (27.9)	189 (32.2)
	TAVI alone	82.9±0.39	812 (46.1)			1125 (63.9)				560 (31.8)	526 (29.9)
Paradis et al 2017[41]	TAVI+PCI	N/A	39 (39.8)	N/A	N/A	SYNTAX	N/A	N/A	N/A	N/A	N/A
	TAVI alone		160 (56.3)			22.0 18.5					

Data presented as number/sample size (percentage), mean±SD or median (interquartile range). CAD indicates coronary artery disease; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; Log-EuroSCORE, logistic European system for cardiac operative risk evaluation; LVEF, left ventricle ejection fraction; N/A, not available; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; STS score, Society of Thoracic Surgeons Score for Prediction of Mortality score; SYNTAX, Synergy Between PCI With Taxus and Cardiac Surgery; TAVI, transcatheter aortic valve implantation.

DOI: 10.1161/JAHA.117.005960

Table 3. Newcastle-Ottawa Quality Assessment Scale

Study	Sample Size >50 in Each Arm	Selection Bias				Comparability	Ascertainment and Attrition Bias			Overall Quality
		Representativeness of Exposed Cohort for TAVI Population	Selection of Non-Exposed Cohort	Method of Exposure Ascertainment	Outcome of Interest Present at Start?	Adjustment for Important Confounders	Outcome Ascertainment (Source, Criteria)	Adequate Length of Follow-up	Loss to Follow-up <10%	
Masson et al 2010[9]	No, 15 and 89	Yes	All in our analysis had CAD of varying severity	Preoperative coronary angiography and Duke Myocardial Jeopardy score	No	Both groups in our analysis had 100% CAD but no other adjustments	Clinical appointment follow-up but adjudication not according to standardized end points	Yes	Yes, unclear	Average
Conradi et al 2011[23]	No, 28	Yes	All had CAD	Preoperative coronary angiography	No	Both groups had 100% CAD but no other adjustments	Telephone interviews but no adjudication according to guidelines	Yes	Yes, none	High
Gautier et al 2011[11]	No, 11 and 72	Yes	All had CAD	Preoperative coronary angiography	No	No adjustment	Unclear, but adjudicated according to guidelines for reporting mortality and morbidity in TAVI	Yes	Yes, none	Average
Nowakowski et al 2011[22]	No, 15 and 55	Yes	No information on CAD prevalence	Unclear	Unclear	No reporting of CAD percentage in each arm or other adjustments	Unclear	Unclear	Unclear	Low
Wenaweser et al 2011[10]	Yes, 59 and 197	Yes	Dissimilar CAD distribution between exposed and non-exposed cohorts	Preprocedural left heart catheterization	No	No adjustments, imbalance in CAD between arms	Data from municipal civil registries and hospital records; data recorded in accordance with VARC guidelines but version is unclear	Yes	Yes, none	Average
Abdel-Wahab et al 2012[12]	Yes, 55 and 70	Yes	Nonexposed cohort had different rate of CAD	Preoperative coronary angiography	No	No, not controlling for CAD	No information on source employed; outcomes adjudicated in accordance with VARC-1 guidelines	Yes	Yes, 0.8% loss to follow-up	Average

Continued

DOI: 10.1161/JAHA.117.005960

Table 3. Continued

Study	Sample Size >50 in Each Arm	Selection Bias				Comparability	Ascertainment and Attrition Bias			Overall Quality
		Representativeness of Exposed Cohort for TAVI Population	Selection of Non-Exposed Cohort	Method of Exposure Ascertainment	Outcome of Interest Present at Start?	Adjustment for Important Confounders	Outcome Ascertainment (Source, Criteria)	Adequate Length of Follow-up	Loss to Follow-up <10%	
Bensaid et al 2012[24]	No, 23 and 38	Yes	No information on CAD prevalence	Preoperative coronary angiography	Unclear	CAD percentage same in both groups but no other adjustments	Unclear source and adjudication guidelines	Yes	Unclear	Low
Aktug et al 2013[25]	Yes, 66 and 272	Yes	Dissimilar CAD distribution between exposed and nonexposed cohorts	Unclear	No	No, not controlling for CAD or other factors	Unclear source and adjudication guidelines	Yes	Unclear	Low
Arnold et al 2013[26]	Yes, 73 and 227	Yes	No information on CAD prevalence	Unclear	Unclear	No, not controlling for CAD or other factors	Unclear	Yes	Unclear	Low
Codner et al 2013[27]	No, 36 and 117	Yes	No separate information on CAD prevalence	Preoperative coronary angiography	No	No adjustments	Participants prospectively examined; data recorded in accordance with VARC-1 criteria	Yes	Yes, none	Average
Czerwinska-Jelonkiewicz et al 2013[30]	No, 18 and 65	Yes	No information on CAD prevalence	Unclear	No	No adjustments	Telephone interviews; data recorded in accordance with VARC-1 criteria	Yes	Yes, 2.4% loss to follow-up	Low
Gasparetto et al 2013[28]	No, 39 and 113	Yes	All had CAD	Preoperative coronary angiography or history	No	No adjustments	Unclear; data recorded in accordance with VARC-1 criteria	Yes	Yes, none.	Average
Van Mieghem et al 2013[29]	No, 39 and 99	Yes	Unclear	Preoperative coronary angiography	No	No adjustments	Clinical follow-up; VARC-1 criteria	Yes	Yes, none	Average
Abramowitz et al 2014[31]	Yes, 61 and 83	Yes	Nonexposed cohort similar to exposed in terms of CAD	Preprocedural coronary angiography	No	Yes, controlling for CAD	Outcomes prospectively recorded in clinical assessments employing VARC-1 guidelines	Yes	Yes, none	High

Continued

DOI: 10.1161/JAHA.117.005960

Table 3. Continued

Study	Sample Size >50 in Each Arm	Selection Bias				Comparability	Ascertainment and Attrition Bias			Overall Quality
		Representativeness of Exposed Cohort for TAVI Population	Selection of Non-Exposed Cohort	Method of Exposure Ascertainment	Outcome of Interest Present at Start?	Adjustment for Important Confounders	Outcome Ascertainment (Source, Criteria)	Adequate Length of Follow-up	Loss to Follow-up <10%	
Griese et al 2014[33]	Yes 65 and 346	Yes	No information on CAD prevalence	Preoperative cardiac catheterization	No	No adjustment and CAD percentage unreported	Yes, phone calls; data recorded in accordance with VARC-2 criteria	Yes	Yes, 100% follow-up	Average
Tatar et al 2014[32]	Yes, 38 and 103	Yes	Nonexposed cohort had different rate of CAD	Unclear	No	No adjustments, imbalance in CAD between arms	Unclear	Yes	Yes, none	Low
Khawaja et al 2015[37]	No, 25 and 68	Yes	All patients in analyzed subgroup had CAD	Pre-TAVI coronary angiogram and SYNTAX score calculation	No	In the subgroup analysis, all patients had CAD but no other adjustments	Database with outcomes reported according to VARC-2 criteria	Yes	Yes, none	High
Mancio et al 2015[34]	No, 13 and 33	Yes	All had CAD	Preprocedural coronary angiography	No	100% CAD in both groups, no other adjustments	Unclear	Yes	Yes, none	High
Penkalla et al 2015[35]	Yes, 76 and 232	Yes	Information on CAD present and stratified according to significance	Pre-TAVI coronary angiogram and SYNTAX score calculation	No	Adjusted for comparison between groups II and III, as they all had CAD; no other adjustments	Mortality ascertained from German Register of Residents and clinical outcomes from prospective e-database; ascertainment according to VARC-2 consensus guidelines	Yes	Unclear	High
van Rosendael et al 2015[36]	No, 96	Yes	All had CAD	Preoperative coronary angiograms with SYNTAX score calculation	No	No adjustments	Electronic record keeping, using VARC-2 criteria	Yes	Yes, none	Average
Snow et al 2015[38]	Yes, 172 and 2416	Yes	Unequal CAD distribution between exposed and nonexposed	Pre-TAVI coronary angiogram	No	No adjustments	Prospectively entered data from electronic BCIS and SCTS database; data linked to the Office of National Statistics and	Yes	Unclear	Average

Continued

DOI: 10.1161/JAHA.117.005960

Table 3. Continued

Study	Sample Size >50 in Each Arm	Selection Bias				Comparability	Ascertainment and Attrition Bias			Overall Quality
		Representativeness of Exposed Cohort for TAVI Population	Selection of Non-Exposed Cohort	Method of Exposure Ascertainment	Outcome of Interest Present at Start?	Adjustment for Important Confounders	Outcome Ascertainment (Source, Criteria)	Adequate Length of Follow-up	Loss to Follow-up <10%	
							National Records of Scotland			
Chakravarty et al 2016[39]	Yes, 128 and 128	Yes	No information on CAD prevalence but matched for unprotected left main stem	Preoperative coronary angiography and CT scans	No	Matched control subjects	Data from registry, recorded in accordance with VARC-2 guidelines	Yes	Yes, none	High
Singh et al 2016[40]	Yes, 588 and 1761	Yes	Unequal CAD distribution between the 2 groups	No information on how significance was determined	Unclear	Propensity matching for some confounders but not for CAD	Outcomes ascertained via the Nationwide Inpatient sample; ICD-9 codes used	Unclear	Yes, none	Average
Paradis et al 2017[41]	Yes, 98 and 285	Yes	No information on CAD prevalence	Pre-TAVI coronary angiogram	Unclear	Multivariate analysis for mortality but not for other outcomes; no data on variables included in the model	Adjudicated outcomes according to VARC-1 definition by clinical event committee	Yes	Unclear	Average

BCIS indicates British Cardiovascular Intervention Society; CAD, coronary artery disease; ICD-9, *International Classification of Diseases, Ninth Revision*; SCTS, Society of Cardiothoracic Surgeons; TAVI, transcatheter aortic valve implantation; VARC, Valve Academic Research Consortium.

DOI: 10.1161/JAHA.117.005960

Table 4. Procedure-Related Complications and Follow-up Clinical Outcome

Study	Type of Valve Approach	Timing of PCI	Outcomes	TAVI+PCI		TAVI Alone
Masson et al 2010[9]	Edwards SAPIEN (100%) Transfemoral: 82/119 (69%)	A priori Median: 26 d Range: 3–100 d	30-ay mortality	0/15 (0)		12/89 (14)
			1-y mortality	3/15 (20)		26/89 (29)
Conradi et al 2011[23]	Medtronic CoreValve Edwards SAPIEN Transapical: 17/28 (61%) Transfemoral: 11/28 (39%)	Concomitant and a priori up to 4 w before TAVI		Concomitant	A priori	
			Procedural and 30-d mortality	2/7 (29)	0/21 (0)	N/A
			AKI	2/7 (29)	0/21 (0)	
			Nonsevere bleeding	0/7 (0)	2/21 (10)	
Gautier et al 2011[11]	Medtronic CoreValve Edwards SAPIEN Transfemoral Trans-subclavian	Concomitant and a priori, mean delay 6±6 w	30-d mortality	8/83 (9.6)		
			Stroke	2/83 (2.4)		
			MI	8/83 (9.6)		
			Severe bleeding	5/83 (6.0)		
			Vascular complications	9/83 (11)		
Nowakowski et al 2011[22]	N/A	Concomitant and a priori, at least 6 w prior to TAVI in all but 6 patients		Concomitant	A priori	N/A
			Stroke	0/6 (0)	1/9 (11.1)	
			AKI	0/6 (0)	2/9 (22)	
			Vascular complications	1/6 (17)	0/9 (0)	
Wenaweser et al 2011[10]	Medtronic CoreValve Edwards SAPIEN Transfemoral Trans-subclavian Transapical	Concomitant and a priori		Concomitant	A priori	
			30-d mortality	4/36 (11)	2/23 (8.7)	11/197 (5.6)
			30-d cardiovascular mortality	3/59 (5.1)		9/197 (4.6)
			30-d stroke	2/36 (5.6)	0/23 (0)	8/197 (4.1)
			30-d MI	0/36 (0)	0/23 (0)	1/197 (0.5)
			Life-threatening bleeding	2/36 (5.6)	3/23 (13)	24/197 (12)
			Major bleeding	21/59 (36)		57/197 (29)
			Major access site–related complication	1/36 (2.8)	3/23 (13)	12/197 (6.1)
			Minor access site–related complication	5/59 (8.5)		18/197 (9.1)
			Combined safety end point	8/36 (22)	6/23 (26)	61/197 (31)
			AKI (I, II, and III)	8/59 (14)		35/197 (18)
			Permanent pacemaker implantation	14/59 (24)		46/197 (23)
			30-d mortality	1/55 (1.8)		4/70 (5.7)

Continued

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Table 4. Continued

Study	Type of Valve Approach	Timing of PCI	Outcomes	TAVI+PCI	TAVI Alone
Abdel-Wahab et al 2012[12]	Medtronic CoreValve Transfemoral: 124/125 (99.2%) Trans-subclavian: 1/125 (0.8%)	A priori Median: 10 d Range: 0–90 d	30-d cardiovascular mortality	1/55 (1.8)	3/70 (4.3)
			30-d stroke	1/55 (1.8)	4/70 (5.7)
			30-d MI	0/55 (0)	0/70 (0)
			30-d life threatening bleeding	4/55 (7.3)	4/70 (5.7)
			30-d major bleeding	6/55 (11)	8/70 (11)
			30-d minor bleeding	4/55 (7.3)	3/70 (4.3)
			30-d major vascular complications	3/55 (5.5)	2/70 (2.9)
			30-d minor vascular complications	8/55 (15)	10/70 (14)
			30-d combined safety end point	6/55 (11)	9/70 (13)
			30-d permanent pacemaker	16/55 (30)	11/70 (16)
			30-d hemodialysis	0/55 (0)	2/70 (2.9)
			6-Month mortality	4/48 (8.3)	8/59 (14)
			6-Month coronary events	2/48 (4.2)	0/59 (0)
			6-Month stroke	2/48 (4.2)	3/59 (5.1)
			6-Month bleeding	10/48 (21)	13/59 (22)
			6-Month permanent pacemaker	16/48 (33)	11/59 (19)
			6-Month hemodialysis	0/48 (0)	1/59 (1.7)
Bensaid et al 2012[24]	Medtronic CoreValve	A priori 1 Month prior to TAVI	Composite of heart failure, MI, and mortality	6/23 (26)	12/38 (32)
Aktug et al 2013[25]	Medtronic CoreValve: 183/338 (54.1%) Edwards SAPIEN: 146/338 (43.2%) Symetis Acurate: 9/338 (2.7%)	Concomitant and a priori Mean: 13±9 d	30-d mortality	8/66 (12)	27/272 (9.9)
Arnold et al 2013[26]	Balloon-expandable valve Transapical: 200/300 (66.7%) Transfemoral: 100/300 (33.3%)	N/A	30-d mortality	8/73 (11)	26/227 (12)
			Long-term mortality	25/73 (34)	59/227 (26)
Codner et al 2013[27]	Medtronic CoreValve Edwards-SAPIEN Transfemoral: 112/153 (73.2%) Transapical: 27/153 (17.6%) Transaxillary: 13/153 (8.5%) Transaortic: 1/153 (0.6%)	Concomitant and a priori	1-y mortality	5/36 (14)	8/117 (6.8)

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DOI: 10.1161/JAHA.117.005960

Table 4. Continued

Study	Type of Valve Approach	Timing of PCI	Outcomes	TAVI+PCI	TAVI Alone
Czerwinska-Jelonkiewicz et al 2013[30]	Medtronic CoreValve Edwards SAPIEN/SAPIEN-XT Transfemoral 59/83 (71%) Trans-subclavian 8/83 (9.6%) Transapical 16/83 (19.2%)	N/A	Bleeding complications	17/18 (94)	34/65 (52)
Gasparetto et al 2013[28]	Medtronic CoreValve Edwards SAPIEN/SAPIEN-XT Transfemoral Trans-subclavian	A priori Median: 27 (IQR 8–51) d	30-d mortality	N/A	5/113 (4.4)
			30-d cardiovascular mortality	N/A	6/113 (5.3)
			30-d Stroke	N/A	3/113 (2.7)
			30-d MI	N/A	5/113 (4.4)
			30-d life-threatening bleeding	N/A	4/113 (3.5)
			30-d major vascular complications	N/A	7/113 (6.2)
			30-d combined safety end point	N/A	12/113 (11)
			30-d AKI (stage III)	N/A	6/113 (5.3)
			1-y mortality	N/A	16/106 (15)
			1-y cardiovascular mortality	N/A	4/106 (3.8)
			1-y major stroke	N/A	1/106 (0.9)
			1-y MI	N/A	2/106 (1.9)
			1-y major bleeding	N/A	1/106 (0.94)
Van Mieghem et al 2013[29]	Medtronic CoreValve Edwards SAPIEN Transfemoral Transaxillary, Transapical	Concomitant and a priori	N/A	N/A	N/A
Abramowitz et al 2014[31]	Medtronic CoreValve Edwards SAPIEN Transfemoral Trans-subclavian	A priori Mean: 56.5±29.4 d	30-d mortality	1/61 (1.6)	2/83 (2.4)
			30-d stroke	2/61 (3.3)	2/83 (2.4)
			30-d MI	0/61 (0)	0/83 (0)
			30-d major bleeding	2/61 (3.3)	1/83 (1.2)
			30-d major vascular complications	3/61 (4.9)	2/83 (2.4)
			30-d minor vascular complications	9/61 (15)	4/83 (4.8)
			30-d combined safety end point	5/61 (8.2)	5/83 (6.0)
			30-d permanent pacemaker	13/61 (21.3)	22/83 (26.5)
			30-d hemodialysis	0/61 (0)	0/83 (0)

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Table 4. Continued

Study	Type of Valve Approach	Timing of PCI	Outcomes	TAVI+PCI		TAVI Alone
Griese et al 2014[33]	Medtronic CoreValve Edwards SAPIEN-XT Symetis Acurate Transfemoral: 190/411 (46.2%) Transapical: 221/411 (53.8%)	Concomitant and a priori, 36±38 d		Concomitant	A priori	
			30-d mortality	3/17 (18)	7/48 (15)	18/346 (5.2)
			30-d cardiovascular mortality	3/17 (18)	7/48 (15)	18/346 (5.2)
			30-d stroke	0/17 (0)	0/48 (0)	6/346 (1.7)
			30-d MI	2/17 (12)	2/48 (4.2)	3/346 (0.9)
			30-d major bleeding	3/17 (17)	7/48 (15)	93/346 (27)
			30-d major vascular complications	0/10 (0)	1/23 (4.4)	8/157 (5.1)
			30-d permanent pacemaker	4/17 (24)	13/48 (27)	76/346 (22)
			30-d stage III AKI	1/17 (5.9)	2/48 (4.2)	20/346 (5.8)
Tatar et al 2014[32]	Medtronic CoreValve: 8/141 (5.7%) Edwards SAPIEN: 126/141 (89.4%) St. Jude Portico: 7/141 (4.96%) Transfemoral: 141/141 (100%)		In hospital mortality	2/38 (5.3)		2/103 (1.9)
			Cardiovascular mortality	1/38 (2.6)		1/103 (1.0)
			Stroke	2/38 (5.3)		1/103 (1.9)
			MI	0/38 (0)		0/103 (0)
			Life-threatening bleeding	0/38 (0)		2/103 (1.9)
			Major bleeding	0/38 (0)		1/103 (1.0)
			Minor bleeding	0/38 (0)		0/103 (0)
			Major vascular complications	1/38 (2.6)		3/103 (2.9)
			Minor vascular complications	0/38 (0)		2/103 (1.9)
			New pacemaker	2/38 (5.3)		10/103 (9.7)
			AKI stage I, II, and III	13/38 (34)		17/103 (17)
			1-y mortality	11/38 (29)		21/103 (20)
			2-y mortality	13/38 (34)		48/103 (47)
Khawaja et al 2015[37]	Edwards SAPIEN Transfemoral: 47/93 (50.5%) Transapical: 29/93 (31.2%) Transaortic: 17/93 (18.3%)	A priori Median: 49.5 (IQR 25–127) d	30-d mortality	2/25 (8)		5/68 (7.4)
			1-y mortality	6/25 (24)		15/68 (22)
Mancio et al 2015[34]	Medtronic CoreValve Edwards SAPIEN Transfemoral Transapical Trans-subclavian	Concomitant (2/13) and a priori (11/13) Median: 56 (IQR 3–166) d	30-d mortality	2/13 (15)		4/33 (12)
			30-d stroke	1/13 (7.7)		1/33 (3.0)
			30-d life-threatening bleeding	2/13 (15)		10/33 (30)
			30-d major vascular complications	2/13 (15)		11/33 (33)
			30-d AKI	4/13 (31)		10/33 (30)

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DOI: 10.1161/JAHA.117.005960

Table 4. Continued

Study	Type of Valve Approach	Timing of PCI	Outcomes	TAVI+PCI		TAVI Alone
			30-d permanent pacemaker	3/13 (23)		13/33 (39)
Penkalla et al 2015[35]	Edwards SAPIEN (100%) Transapical (100%)	Concomitant	30-d mortality	2/76 (2.6)		9/232 (3.9)
			Peri- and postprocedural MI	1/76 (1.3)		4/232 (1.7)
			AKI stage I and III	16/76 (21)		43/232 (19)
			1-y mortality	30/76 (40)		94/232 (41)
			2-y mortality	46/76 (61)		151/232 (65)
			3-y mortality	63/76 (83)		188/232 (81)
			4-y mortality	73/76 (96)		221/232 (95)
van Rosendael et al 2015[36]	Medtronic CoreValve Edwards SAPIEN Transfemoral Transapical	A priori		A priori ≥30 d	A priori <30 d	
			In-hospital death	4/48 (8.3)	2/48 (4.2)	N/A
			30-d stroke	1/48 (2.1)	1/48 (2.1)	
			30-d major bleeding	4/48 (8.3)	4/48 (8.3)	
			30-d minor bleeding	0/48 (0)	6/48 (13)	
			30-d major vascular injury	3/48 (7.3)	5/48 (10)	
			30-d minor vascular injury	1/48 (2.1)	8/48 (17)	
			30-d combined safety end point	9/48 (19)	6/48 (13)	
			30-d AKI	8/48 (17)	8/48 (17)	
			30-d atrioventricular block	7/48 (7.3)	2/48 (4.2)	
Snow et al 2015[38]	N/A	Concomitant and a priori	1-y mortality	36/172 (21)		246/1167 (21)
Chakravarty et al 2016[39]	Medtronic CoreValve Edwards SAPIEN Direct flow Transfemoral/Trans-subclavian: 194/256 (75.8%) Alternative access: 44/256 (17.2%)	Concomitant and a priori	30-d mortality	4/128 (3.1)		3/128 (2.3)
			30-d stroke	1/128 (0.8)		2/128 (1.6)
			30-d MI	0/128 (0)		0/128 (0)
			Procedural death	0/128 (0)		1/128 (0)
			Procedural major or life-threatening bleeding	22/128 (17)		33/128 (26)
			Procedural major vascular complications	21/128 (16)		5/128 (3.9)
			Permanent pacemaker	34/128 (27)		18/128 (14)
			AKI	6/128 (4.7)		7/128 (5.5)
			1-y mortality	12/128 (9.4)		13/128 (10)
			1-y stroke	1/128 (0.8)		3/128 (2.3)
			1-y MI	3/128 (2.3)		1/128 (0.8)

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DOI: 10.1161/JAHA.117.005960

Table 4. Continued

Study	Type of Valve Approach	Timing of PCI	Outcomes	TAVI+PCI	TAVI Alone
Singh et al 2016[40]	Transfemoral/transaortic (84.6%) Transapical (15.4%)	Concomitant and a priori	In-hospital mortality	60/588 (10)	120/1761 (6.8)
			In-hospital neurological complications	20/588 (3.4)	128/1761 (7.3)
			In-hospital bleeding requiring transfusion	45/588 (7.7)	217/1761 (12)
			In-hospital major vascular complications	50/588 (8.5)	79/1761 (4.5)
			In-hospital AKI requiring dialysis	5/588 (0.9)	44/1761 (2.5)
			In-hospital permanent pacemaker	34/588 (5.8)	190/1761 (11)
Paradis et al 2017[41]	Edwards SAPIEN Transfemoral: 25/54 (44.4%) Transapical: 29/54 (53.7%)	A priori Up to 6 Months before TAVI	30-d mortality	1/54 (1.8)	N/A
			Major bleeding complications	6/54 (11.1)	
			Major vascular complications	5/54 (9.3)	
			Stroke	1/54 (1.8)	
			1-y mortality	3/54 (5.6)	

Data presented as the occurrence of an event/sample size (percentage). AKI indicates acute kidney injury; IQR, interquartile range; MI, myocardial infarction; N/A, not available; PCI, percutaneous coronary intervention; TAVI, transcatheter aortic valve implantation.

Coexisting Coronary Artery Disease

The prevalence of coexisting CAD was reported in both revascularized and nonrevascularized groups in 9 studies,[¶] and varied from 51.4% to 100%. Consequently, we conducted a subgroup analysis of clinical outcomes comparing studies reporting populations with 100% versus >50% (but <100%) of the patients presenting with CAD.

In subgroup analysis including studies in which the prevalence of CAD was 100%, the OR for 30-day mortality among patients who underwent PCI was 0.80 (95% CI, 0.28–2.27), whereas in studies in which the prevalence of CAD was >50% (but <100%), more patients who received PCI died (OR: 1.49; 95% CI, 1.12–1.98; P=0.006; heterogeneity: P=0.45, I^2=0%). The overall difference showed significant effect estimates (OR: 1.42; 95% CI, 1.08–1.87; P=0.01; heterogeneity: P=0.63, I^2=0%) without significant interaction (P=0.65, I^2=20%). No significant differences in effect estimates were observed in terms of cardiovascular (OR: 1.03; 95% CI, 0.35–2.99) and 1-year (OR: 1.05; 95% CI, 0.71–1.56) mortality rates. Similar effect estimates were found for the 2 strategies in the remaining analyzed variables (Figure 5).

Sensitivity analysis comparing random- versus fixed-effects models and excluding studies with no events in one of the treatment arms is shown in Table 6. The results suggest no differences in effect estimates between the 2 models or after excluding studies with no events in one of the treatment arms. Metaregression analysis was conducted to further investigate potential sources of clinical heterogeneity based on the prevalence of CAD. The results rule out a strong magnitude of the effect to influence any of the analyzed outcomes (Table 7).

Discussion

The results of this meta-analysis of 9 observational studies including 3858 patients show that PCI revascularization before (prior to and concomitant) TAVI may be associated with an increased risk of major vascular complications and 30-day mortality, although by 1 year, this association was no longer present. In addition, comparing TAVI with and without revascularization, there were no significant differences in rates of MI, bleeding, AKI/hemodialysis, or cerebrovascular accidents at 30 days. Notably, we found that the evidence basis consists of poor-quality studies confounded by selection bias, thus emphasizing the need for randomized controlled trials.

[¶]References 9, 10, 12, 25, 31, 32, 35, 37, 40.

DOI: 10.1161/JAHA.117.005960

Table 5. Pooled Analysis for Adverse Outcomes With and Without Revascularization

Outcome	Studies	Cumulative	%	References	Studies	TAVI PCI	%	References	Studies	TAVI Alone	%	References
30-d mortality	18	368/5281	6.97	9–12, 23, 25, 26, 28, 31–37, 39–41	16	115/1441	7.98	9, 10, 12, 23, 25, 26, 31–37, 39–41	14	245/3757	6.52	9, 10, 12, 25, 26, 28, 31–35, 37, 39, 40
30-d cardiovascular mortality	5	52/1046	4.97	10, 12, 28, 32, 33	4	15/217	6.91	10, 12, 32, 33	5	37/829	4.46	10, 12, 28, 32, 33
1-y mortality	9	545/2554	21.3	9, 27, 28, 32, 35, 37–39, 41	7	106/544	19.5	9, 27, 32, 35, 37–39, 41	8	439/2010	21.8	9, 27, 28, 32, 35, 37–39
2-y mortality	2	258/449	57.5	32, 35	2	59/114	51.8	32, 35	2	199/335	59.4	32, 35
Myocardial infarction	10	26/3109	0.84	10–12, 28, 31–33, 35, 39	8	5/482	1.0	10, 12, 31–33, 35, 39	8	13/1272	1.02	10, 12, 28, 31–33, 35, 39
Major or life-threatening bleeding	12	590/4074	14.5	10–12, 28, 31–34, 36, 39–41	10	131/1157	11.3	10, 12, 31–34, 36, 39–41	9	454/2834	16.0	10, 12, 28, 31–34, 39, 40
Major vascular complications	11	227/3770	6.02	10, 12, 28, 31–34, 36, 39–41	10	98/1125	8.7	10, 12, 31–34, 36, 39–41	9	129/2645	4.9	10, 12, 28, 31–34, 39, 40
Acute kidney injury	13	259/4288	6.04	10, 12, 22, 23, 28, 31–36, 39, 40	12	75/1222	6.13	10, 12, 22, 23, 31–36, 39, 40	10	184/3066	6.0	10, 12, 28, 31–35, 39, 40
Stroke/transient ischemic attack	11	41/1686	2.43	10–12, 22, 28, 31–34, 36, 39	9	12/530	2.26	10, 12, 22, 31–34, 36, 39	8	27/1073	2.5	10, 12, 28, 31–34, 39
Pacemaker implantation	8	443/3382	13.1	10, 12, 31–34, 39, 40	8	120/959	12.5	10, 12, 31–34, 39, 40	8	323/2423	13.3	10, 12, 31–34, 39, 40

Values are expressed as the occurrence of an event/sample size. PCI indicates percutaneous coronary intervention; TAVI, transcatheter aortic valve implantation.

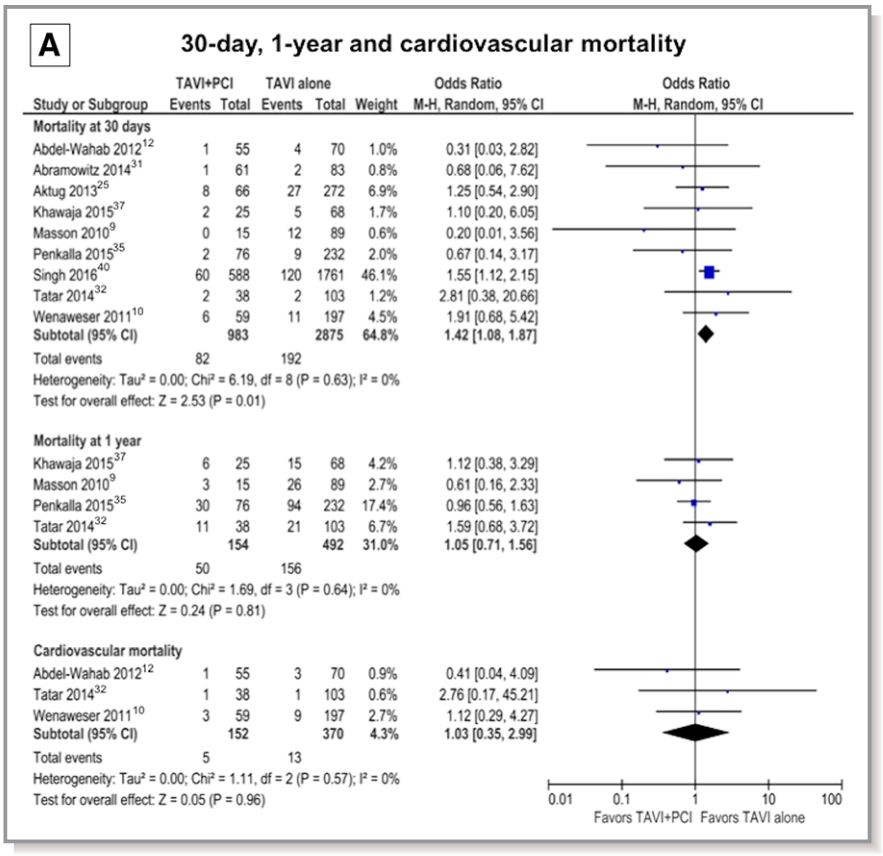

Figure 2. Meta-analyses evaluating the cumulative risk of (A) mortality and (B) clinical outcomes of patients undergoing transcatheter aortic valve implantation (TAVI) plus percutaneous coronary intervention (PCI) vs TAVI alone. AKI indicates acute kidney injury; CI, confidence interval; M-H, Mantel-Haenszel.

Assessing the Severity of CAD in Patients Undergoing TAVI

The optimal treatment of CAD in patients with TAVI remains to be elucidated. Although Dewey et al[8] showed that CAD is an independent predictor of early and midterm survival, this finding was not supported by other studies.[37,38,42,43] In addition, Khawaja and colleagues[37] showed that CAD was not a predictor of worse outcome, albeit in patients exhibiting a SYNTAX (Synergy Between PCI With Taxus and Cardiac Surgery) score >9. Chauhan and colleagues[43] found no significant association between the SYNTAX or Duke Myocardial Jeopardy score with rates of their prespecified primary composite end point (all-cause mortality, major adverse cardiovascular and cerebrovascular event, and postoperative coronary revascularization) or secondary outcomes of the 30-day and 1-year composite end point. Moreover, the authors went further and questioned the role of coronary angiography as part of the TAVI workup.[43] More recently, Paradis and colleagues[41] showed that neither the severity of CAD nor the residual SYNTAX score after revascularization was associated with worse outcomes at 30 days and 1 year after TAVI.

As mentioned previously, the reported prevalence of CAD in the population undergoing TAVI varies depending on the definitions used to define significance (Table 1) and can be as high as 75%.[8–12] The severity of CAD in AS patients has historically been assessed using angiography to further determine the need for revascularization; however, it is well known that functionally guided fractional flow reserve PCI strategies have shown improvements in patient outcome.[44] Nonetheless, functional assessment of CAD in the presence of AS becomes difficult due to diffuse subendocardial ischemia leading to myocardial fibrosis as well as left ventricular remodeling and, often, severe hypertrophy.[45,46] Consequently, coronary physiology is altered in patients with severe AS, and although the use of fractional flow reserve has not been validated for this group, fractional flow reserve has been performed safely in contemporaneous studies of patients with severe AS.[47–51]

Coronary Revascularization and TAVI Outcomes

Our meta-analysis suggests that routine revascularization of patients with severe AS and concomitant CAD undergoing

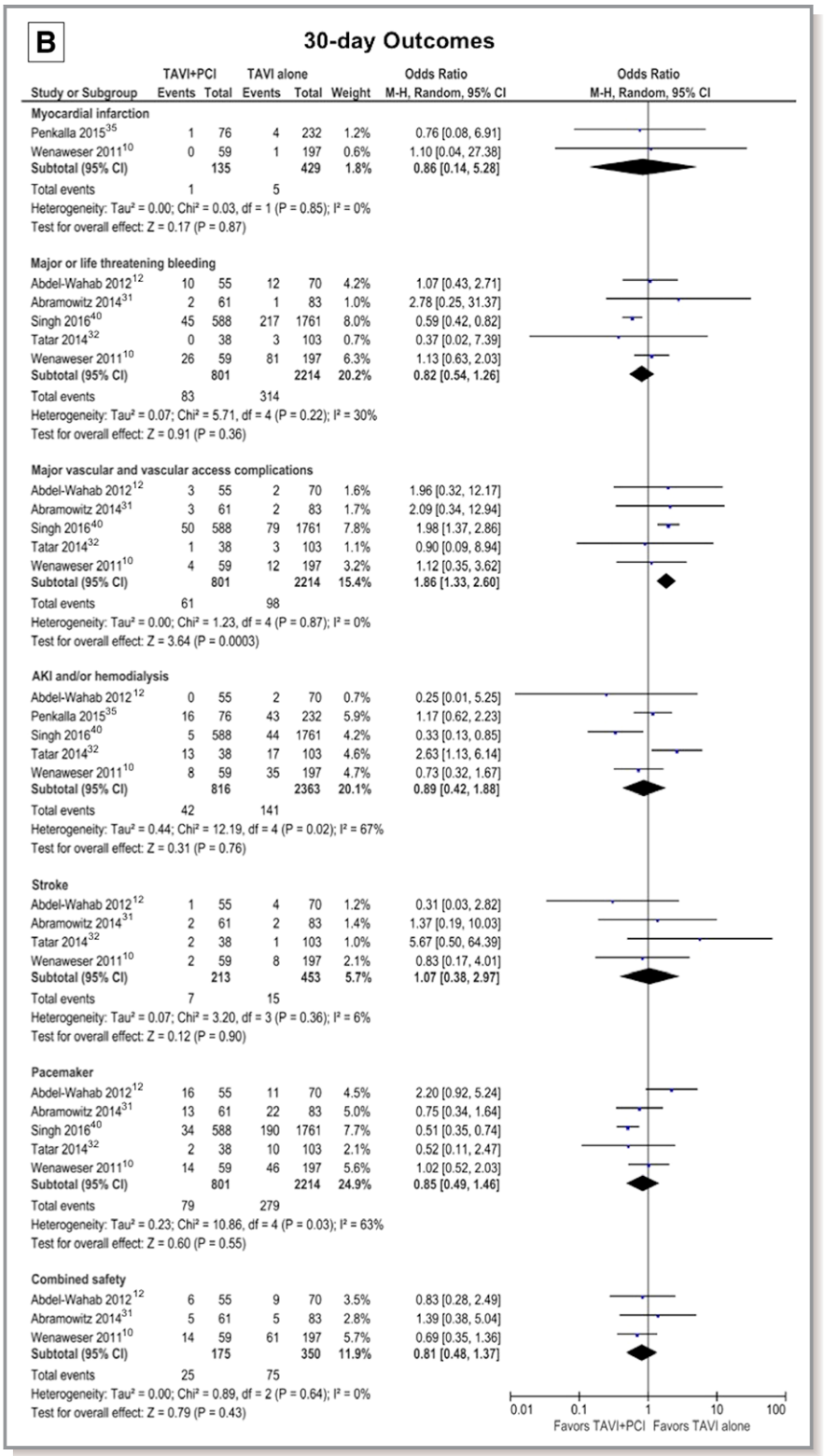

Figure 2. Continued.

TAVI may be associated with an increased risk of major vascular complications and 30-day mortality, although the latter association was no longer present by 1 year. In this regard, Van Mieghem et al[29] have shown no significant difference between complete versus incomplete revascularization or for SYNTAX scores ≥8 versus <8. One of the theoretical arguments to support revascularization prior to TAVI is the anxiety that periprocedural MI might occur during

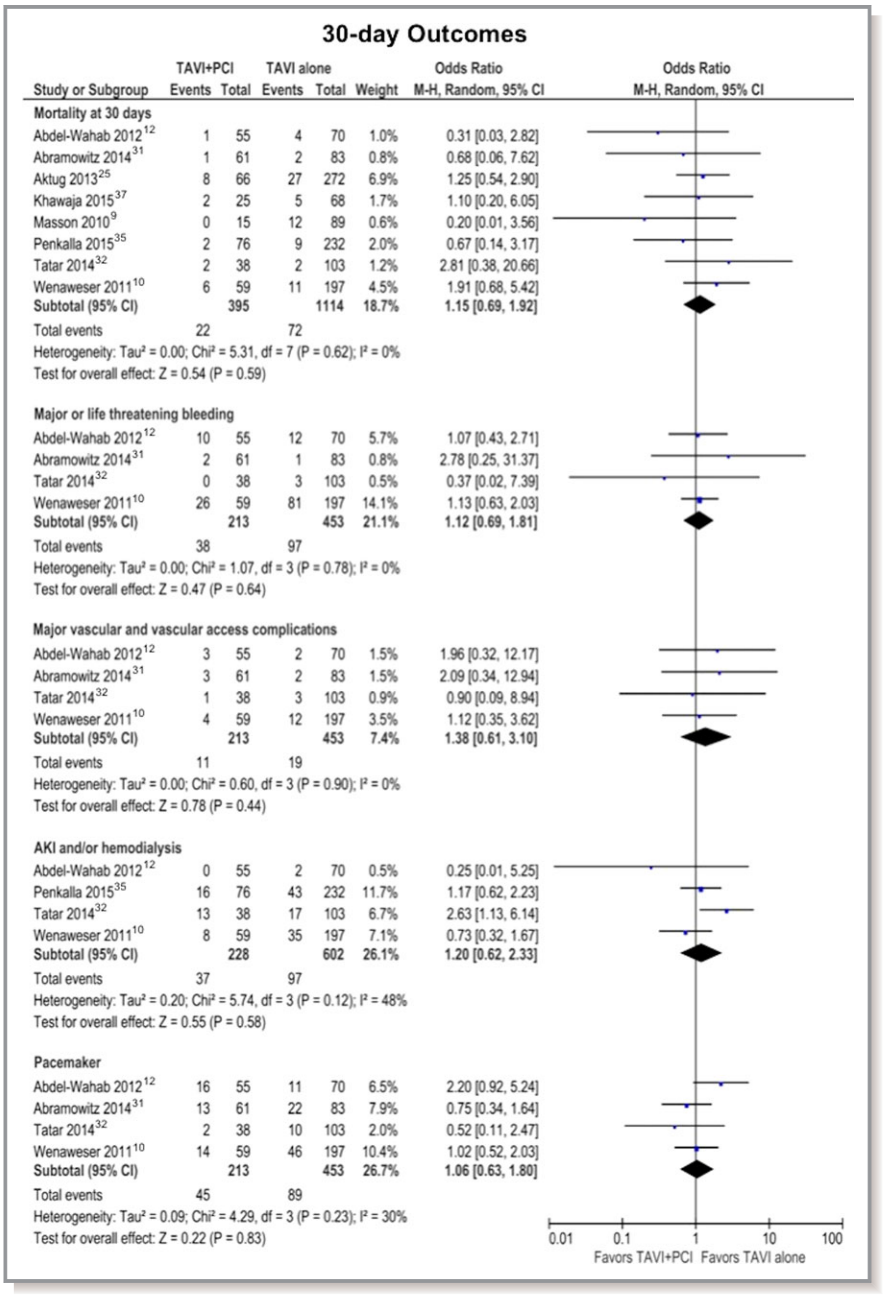

Figure 3. Sensitivity analysis evaluating the cumulative risk of outcomes of patients undergoing transcatheter aortic valve implantation (TAVI) plus percutaneous coronary intervention (PCI) vs TAVI alone. AKI indicates acute kidney injury; CI, confidence interval; M-H, Mantel-Haenszel.

the hypotension induced by rapid pacing for valvuloplasty or during valve delivery. Notably, Griese et al[33] showed that revascularization was associated with increased 30-day MI compared with TAVI alone; however, the study did not ascertain the prevalence of CAD in the TAVI-alone group or, indeed, the indication for PCI. As such, this study was excluded from our meta-analysis. Singh and colleagues[40] showed worse 30-day outcomes when PCI was performed during the same admission, although, as above mentioned, this observation might have been driven by the difference in the reported prevalence of CAD between groups or by a questionable definition of CAD using *International Classification of Diseases, Ninth Revision* coding. Higher 30-day mortality could also be associated with a higher preoperative risk profile, meaning that the PCI group may have been a higher risk cohort, translating into worse outcome; however, the authors did not report adjusting for preprocedural risk scoring. Importantly, our analysis shows that when both

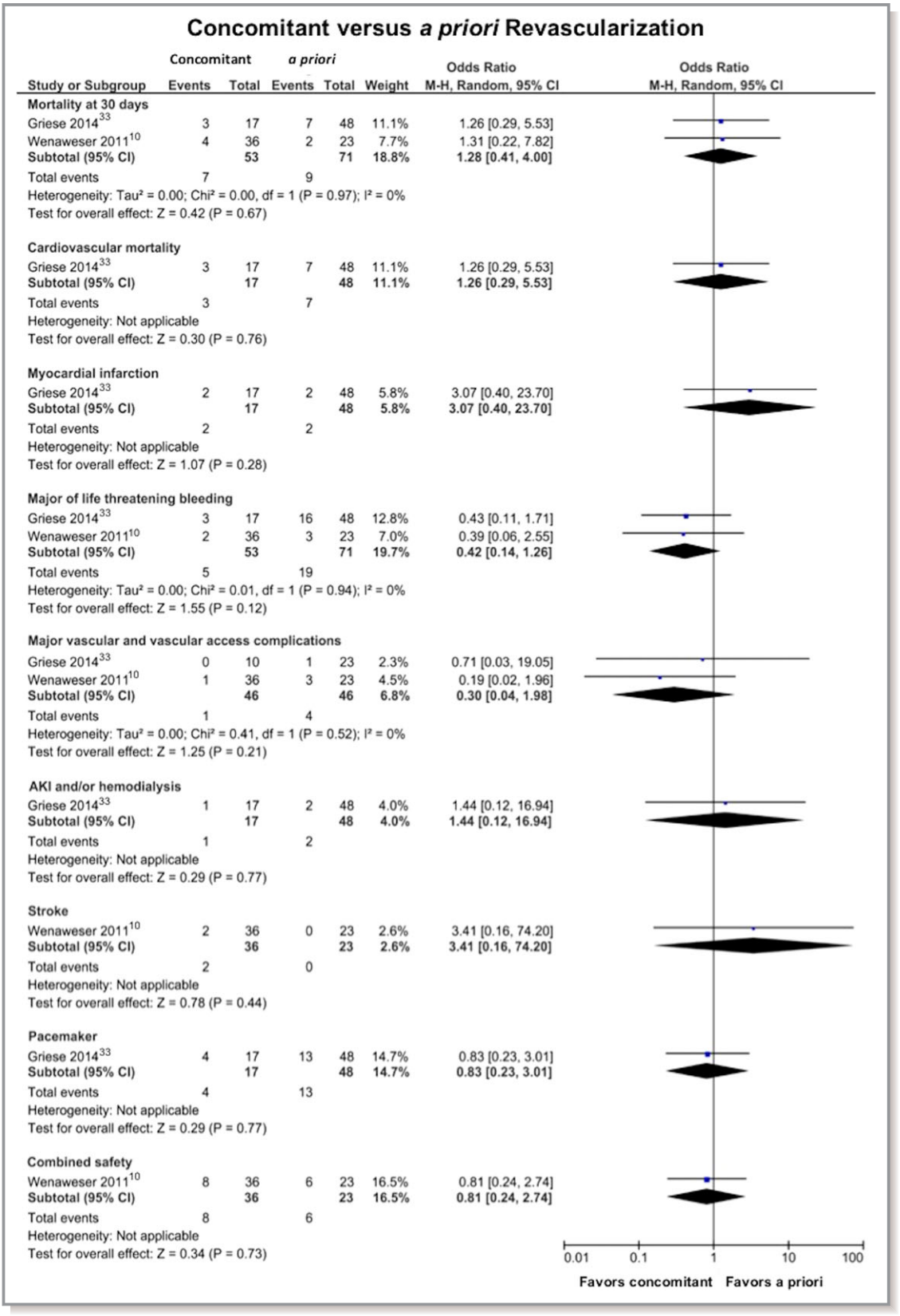

Figure 4. Meta-analyses evaluating outcomes between concomitant (same-setting) vs a priori revascularization of patients undergoing transcatheter aortic valve implantation plus percutaneous coronary intervention. CI indicates confidence interval; M-H, Mantel-Haenszel.

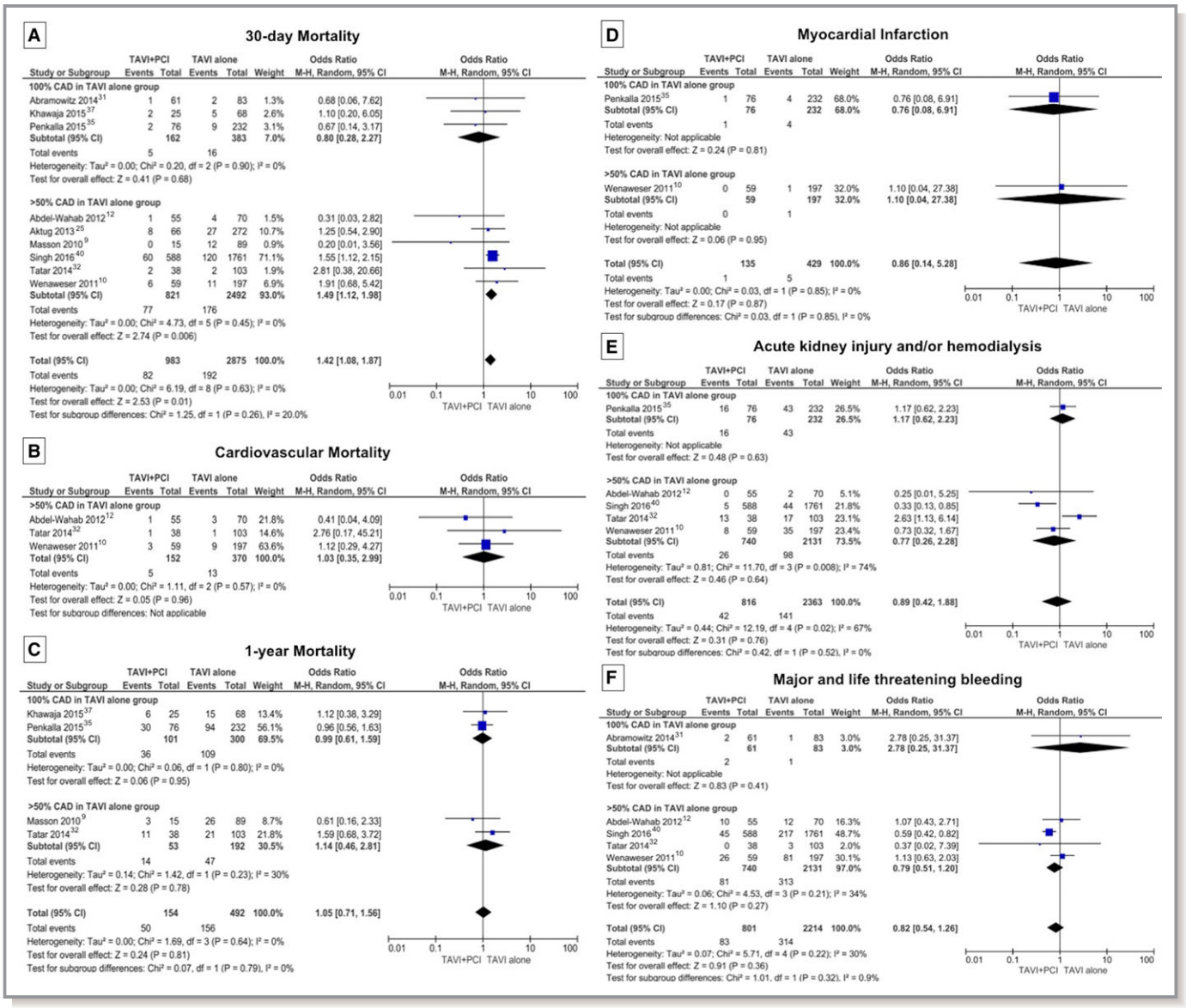

Figure 5. Subgroup analysis according to the prevalence of significant coronary artery disease (CAD) evaluating the cumulative risk of (A) 30-day mortality, (B) cardiovascular mortality, (C) 1-year mortality, (D) myocardial infarction, (E) acute kidney injury and/or need for hemodialysis, and (F) major and life-threatening bleeding of patients undergoing transcatheter aortic valve implantation (TAVI) plus percutaneous coronary intervention (PCI) vs TAVI alone. CI indicates confidence interval; M-H, Mantel-Haenszel.

groups had 100% prevalence of CAD, there was no significant difference in treatment effect estimates, likely due to a small event rates (Figure 2A). Moreover, metaregression analysis suggests that differences in the prevalence of CAD did not influence this outcome. Finally, the presence of multiple comorbid conditions explains overall 30-day mortality, since cardiovascular mortality was similar.

Timing for Revascularization: Concomitant Versus A Priori Approach

Performing TAVI shortly after PCI mandates that the TAVI procedure be performed while a patient is treated with dual antiplatelet therapy, potentially increasing bleeding risk; however, our analysis shows that major and minor bleeding complications were not significantly different between pre-TAVI PCI and isolated TAVI approaches. Studies that compared concomitant and a priori revascularization approaches found no significant differences for AKI and the need for hemodialysis.[10,23,33] Interestingly, one would expect that the likelihood of AKI increases with a concomitant approach, owing to the larger contrast volumes and higher number of catheter manipulations; however, as reported previously, contrast amount per se was not associated with AKI during TAVI procedures.[52] In addition, in most studies that reported the incidence of AKI, PCI was performed a priori rather than in

Table 6. Sensitivity Analysis for Clinical Outcomes Comparing the Percentage of Reported CAD in Studies Without Revascularization

Outcome	Random Effects Odds Ratio (95% CI)	Fixed Effects Odds Ratio (95% CI)	Random-Effects Odds Ratio Excluding Studies With No Events in at Least 1 Arm
30-d mortality	1.42 (1.08–1.87)	1.37 (1.04–1.80)	1.45 (1.10–1.91)
100% CAD in TAVI alone group	0.80 (0.28–2.27)	0.80 (0.28–2.24)	0.80 (0.28–2.27)
>50% CAD in TAVI alone group	1.49 (1.12–1.98)	1.43 (1.08–1.90)	1.52 (1.14–2.02)
1-y mortality	1.05 (0.71–1.56)	1.04 (0.70–1.54)	1.05 (0.71–1.56)
100% CAD in TAVI alone group	0.99 (0.61–1.59)	0.99 (0.61–1.59)	0.99 (0.61–1.59)
>50% CAD in TAVI alone group	1.14 (0.46–2.81)	1.17 (0.58–2.36)	1.14 (0.46–2.81)
Cardiovascular mortality	1.03 (0.35–2.99)	0.98 (0.34–2.81)	1.03 (0.35–2.99)
>50% CAD in TAVI alone group	1.03 (0.35–2.99)	0.98 (0.34–2.81)	1.03 (0.35–2.99)
Myocardial infarction	0.86 (0.14–5.28)	0.85 (0.14–5.22)	0.76 (0.08–6.91)
100% CAD in TAVI alone group	0.76 (0.08–6.91)	0.76 (0.08–6.91)	0.76 (0.08–6.91)
>50% CAD in TAVI alone group	1.10 (0.04–27.38)	1.10 (0.04–27.38)	Not estimable
Major or life-threatening bleeding	0.82 (0.54–1.26)	0.72 (0.55–0.94)	0.86 (0.53–1.39)
100% CAD in TAVI alone group	2.78 (0.25–31.37)	2.78 (0.25–31.37)	2.78 (0.25–31.37)
>50% CAD in TAVI alone group	0.79 (0.51–1.20)	0.70 (0.54–0.92)	0.82 (0.50–1.33)
Major vascular or access site complication	1.86 (1.33–2.60)	1.78 (1.31–2.43)	1.86 (1.33–2.60)
100% CAD in TAVI alone group	2.09 (0.34–12.94)	2.04 (0.35–11.84)	2.09 (0.34–12.94)
>50% CAD in TAVI alone group	1.85 (1.32–2.60)	1.77 (1.29–2.43)	1.85 (1.32–2.60)
Acute kidney injury and/or dialysis	0.89 (0.42–1.88)	0.88 (0.61–1.28)	0.95 (0.43–2.08)
100% CAD in TAVI alone group	1.17 (0.62–2.23)	1.17 (0.62–2.23)	1.17 (0.62–2.23)
>50% CAD in TAVI alone group	0.77 (0.26–2.28)	0.77 (0.49–1.22)	0.87 (0.27–2.82)
Stroke	1.07 (0.38–2.97)	1.00 (0.40–2.49)	1.07 (0.38–2.97)
100% CAD in TAVI alone group	1.37 (0.19–10.03)	1.37 (0.19–10.03)	1.37 (0.19–10.03)
>50% CAD in TAVI alone group	1.02 (0.24–4.41)	0.92 (0.32–2.60)	1.02 (0.24–4.41)
Pacemaker implantation	0.85 (0.49–1.46)	0.69 (0.52–0.90)	0.85 (0.49–1.46)
100% CAD in TAVI alone group	0.75 (0.34–1.64)	0.75 (0.34–1.64)	0.75 (0.34–1.64)
>50% CAD in TAVI alone group	0.88 (0.43–1.81)	0.68 (0.51–0.91)	0.88 (0.43–1.81)
Combined safety	0.81 (0.48–1.37)	0.81 (0.48–1.36)	0.81 (0.48–1.37)
100% CAD in TAVI alone group	1.39 (0.38–5.04)	1.39 (0.38–5.04)	1.39 (0.38–5.04)
>50% CAD in TAVI alone group	0.73 (0.41–1.29)	0.73 (0.41–1.29)	0.73 (0.41–1.29)

CAD indicates coronary artery disease; CI, confidence interval; TAVI, transcatheter aortic valve implantation.

the same setting (1 study only; Figures 3 and 4). This finding likely reflects the influence of confounding variables because studies were not statistically powered to infer for AKI due to the low event rate.

The revised American guidelines on valvular heart disease have downgraded to class IIa (evidence C) the role of coronary revascularization at the time of surgical aortic valve replacement.[3] Recommendations focused on TAVI[13–15] while supporting the treatment of significant CAD do not provide suggestions about the timing of PCI relative to the TAVI procedure. Wenaweser et al[10] reported on a combined approach separated into single-stage and staged procedures; later, van Rosendael et al[36] found no differences when comparing revascularization within 30 days prior to TAVI, with PCI performed ≥30 days after TAVI. Thus, there are still very limited data available to inform an optimal strategy with respect to the timing of revascularization.

Limitations

The present study has several limitations. The main limitations are the small numbers of studies, patients, and events informing

Table 7. Metaregression Examining the Influence of CAD on Outcomes

Outcome	Exp(b) (95% CI)	*P* Value
30-d mortality	0.98 (0.94–1.02)	0.23
1-y mortality	0.99 (0.94–1.04)	0.36
Cardiovascular mortality	0.92 (0.15–5.71)	0.68
Myocardial infarction	Insufficient observations	…
Major or life threatening bleeding	1.05 (0.99–1.10)	0.074
Major vascular or access site complication	0.99 (0.91–1.07)	0.72
Acute kidney injury or hemodialysis	1.01 (0.90–1.13)	0.77
Stroke	0.98 (0.74–1.31)	0.81
Permanent pacemaker	1.01 (0.94–1.09)	0.64
Combined safety	1.03 (0.65–1.64)	0.57

CI indicates confidence interval.

each outcome and the nonrandomized nature of the included studies, which introduced selection bias. Importantly, the decision to perform PCI as revascularization versus medical management for CAD was at the discretion of the heart team and without consistent selection criteria. In this regard, the decision to undertake PCI may relate to unstable symptoms, limiting angina, or patients considered to be at higher risk. Individual-patient level data were not available, precluding more robust adjustment for any differences in clinical or anatomical variables or comparisons of severity or risk across the cohorts. Finally, one should bear in mind that once TAVI is extended to lower risk younger and less morbid patients, who also exhibit longer life expectancy, it may be beneficial to perform pre-TAVI revascularization to prevent potential problematic coronary artery accessibility in the future. The results of the ACTIVATION trial[53] will provide further insight into optimal revascularization strategies in patients with CAD undergoing TAVI.

Conclusion

Our findings suggest that revascularization before or during TAVI confers no clinical advantage with respect to several patient-important clinical outcomes and may be associated with an increased risk of major vascular complications and 30-day mortality. These data, however, are based on observational studies including initial high-risk cohorts of patients with limited follow-up and may not be applicable to lower risk cohorts with greater life expectancy. Randomized controlled trials are needed to determine the role of routine revascularization in patients with significant CAD undergoing TAVI. Meanwhile, in the absence of definitive evidence, careful evaluation of patients on an individual basis by a dedicated heart team is of paramount importance to identify patients, such as those with significant CAD affecting proximal main epicardial vessels, for whom the benefits of elective revascularization are balanced against the potential risks.

Sources of Funding

This study was supported in part by a Program of Experimental Medicine (POEM) Research Award, Department of Medicine, Western University, London, Ontario, Canada.

Disclosures

None.

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