Clinical Interventions in Aging Dovepress

Open Access Full Text Article ORIGINAL RESEARCH

Postinduction Hypotension and Adverse Outcomes in Older Adults Undergoing Transcatheter Aortic Valve Replacement: A Retrospective Cohort Study

Ting-Ting Ni, Yuan-Yuan Yao, Xiao-Xia Zhou, Tao Lv, Jing-Cheng Zou, Ge Luo, Jin-Ting Yang, Da-Wei Sun, Qi Gao, Ting-Ting Wang, Rui-Yu Wang, Xin-Chen Tao, Min Yan

Department of Anesthesiology, The Second Affiliated Hospital of Zhejiang University School of Medicine, Hangzhou, Zhejiang, 330100, People's Republic of China

Correspondence: Min Yan, Department of Anesthesiology, The Second Affiliated Hospital of Zhejiang University School of Medicine, No. 88 Jiefang Road, Hangzhou, Zhejiang, 330100, People's Republic of China, Email zryanmin@zju.edu.cn

Purpose: Postinduction hypotension (PIH), occurring between anaesthesia induction and surgical incision, is particularly concerning in older adults undergoing transcatheter aortic valve replacement (TAVR) due to their multiple comorbidities and age-related cardiovascular changes. This study aimed to assess the relationship between PIH and postoperative adverse events in TAVR patients.
Patients and Methods: A total of 777 patients underwent TAVR at The Second Affiliated Hospital of Zhejiang University School of Medicine from January 1, 2020 to February 28, 2023. Four thresholds of MAP were defined, including two absolute thresholds (<65, <60 mmHg) and two relative thresholds (20% and 30% lower than baseline). The relationships between PIH and the composite outcome, which included all-cause in-hospital mortality, stroke, acute kidney injury (AKI), and myocardial infarction (MI), were examined using unadjusted analysis, 1:1 propensity score matching(PSM), and inverse probability of treatment weighting (IPTW).
Results: A total of 643 older adults were included in the study ultimately. The composite outcome incidence was significantly greater in patients with PIH than in those without PIH (relative risk [RR]: 2.47, 95% CI: 1.66–3.73 for MAP <60 mmHg; RR: 1.66, 95% CI: 1.14–2.46 for a >30% decrease from baseline). PIH was significantly associated with stroke (RR: 5.22, 95% CI: 1.98–17.75) and AKI (RR: 2.82, 95% CI: 1.73–4.79) with a MAP <60 mmHg.
Conclusion: PIH significantly increases the risk of composite outcomes, especially stroke and AKI, in TAVR patients.
Keywords: postinduction hypotension, adverse postoperative outcomes, transcatheter aortic valve replacement, older adults

Introduction

Recently, transcatheter aortic valve replacement (TAVR) has been recommended over surgical aortic valve replacement due to its association with more favorable outcomes.[1–3] However, TAVR is still linked to major adverse events in clinical settings, including postoperative acute kidney injury (AKI, 13%), myocardial infarction (MI), transient ischemic attack (TIA)/stroke (3%), and in-hospital mortality (3%).[4] The underlying aetiology is multifactorial, including factors such as age, pre-existing conditions, and surgical procedures.[5–7] Recent research highlights the need to address complications in older adults undergoing TAVR. Jiritano et al[8] found that bleeding complications strongly predict mortality and morbidity in elderly patients, while age did not significantly affect cardiovascular events or mortality, emphasizing frailty as the key factor in managing high-risk patients. Furthermore, intraoperative hypotension (IOH) has been identified as a major contributing factor and is linked to an increased risk of mortality, AKI, MI, or stroke.[9,10] It is important to note that IOH can occur for different reasons depending on the phase of anaesthesia and surgery. Hypotension before surgical incision is largely preventable, whereas intraoperative hypotension is harder to avoid due to its multifactorial causes, such as

Received: 26 August 2024
Accepted: 6 November 2024
Published: 21 November 2024

blood loss, stimuli variation, patient positioning, and vessel compression.[11] We propose examining IOH across different phases to account for the diverse mechanisms underlying TAVR-related outcomes.

Postinduction hypotension (PIH) is defined as a drop in blood pressure between anaesthesia induction and skin incision, primarily due to the vasodilatory effects of anaesthetic drugs, which decrease systemic vascular resistance.[11,12] The incidence of PIH ranges from 9% to 60%.[13–16] Even brief episodes of hypotension can lead to tissue hypoperfusion and subsequent complications, elevating the risk of postoperative morbidity and mortality.[17–19] PIH has garnered significant interest among anaesthesiologists because it is an easily detectable and modifiable factor.

PIH is particularly prevalent among older adults, patients classified as ASAIII–V, those undergoing emergency operations, and individuals on long-term ACEI/ARB therapy.[11,15,16] TAVR patients often present with comorbidities such as coronary artery disease, chronic obstructive pulmonary disease (COPD), and renal insufficiency, which complicates disease management.[20,21] Additionally, age-related cardiovascular changes, including reduced cardiac reserve and increased arterial stiffness, make them more susceptible to hemodynamic instability during anesthesia.[1]

Hypotension is common and linked to adverse outcomes, but inconsistent definitions across studies create uncertainty in identifying clinically significant events. Absolute thresholds, such as <60 mmHg, identify severe hypotension leading to myocardial injury and mortality,[22,23] while relative thresholds, like a 30% drop from baseline, offer a more personalized risk assessment.[24] Our study aimed to analyze the relationship between PIH and postoperative outcomes in TAVR patients using these well-supported thresholds.

The effects of PIH on postoperative outcomes after TAVR have not been thoroughly examined. In this retrospective cohort study, we assessed the association between PIH and adverse outcomes in TAVR patients, hypothesizing that the incidence and severity of PIH are linked to a composite outcome of postoperative mortality, stroke, AKI, and MI.

Materials and Methods

Approvals

This single-centre retrospective cohort study received approval from the Ethics Committee of The Second Affiliated Hospital of Zhejiang University School of Medicine, China (Approval No. 2022–0521, 26 June 2022). Written informed consent was obtained from all study participants or their legal guardians prior to study commencement. The study protocol followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (see Supplementary Appendix). Data analysis and the statistical plan were developed after data access. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Study Participants

This study included adult patients (aged ≥18 years) with a physical classification status according to the American Society of Anaesthesiology (ASA) ofIII–IV who underwent TAVR under either general anaesthesia (GA) or deep sedation anaesthesia at The Second Affiliated Hospital of Zhejiang University School of Medicine, China. The study period was between January 1, 2020, and February 28, 2023. The exclusion criteria were as follows: (1) TAVR was performed through the carotid or apical approach; (2) use of a circulatory assist device before surgery; and (3) missing invasive arterial measurements for > 10 consecutive minutes. Two investigators, unaware of the study's hypothesis, retrieved relevant data from the database via a predetermined form. Patients were categorized into PIH and non-PIH groups based on their MAP following induction of anesthesia according to four hypotension thresholds.

Data Sources and Collection

The data for this study were sourced from the electronic medical record (EMR) system and the Docare anesthesia system. These records encompassed a comprehensive range of patient information, including primary team notes, specialty consultations, imaging results, laboratory values, perioperative evaluations, intraoperative surgical and anesthesia records, postoperative notes, intensive care unit (ICU) nursing notes, and inpatient orders.

The collected data included baseline characteristics, anesthesia and procedural data, and postoperative outcomes. Baseline characteristics comprised clinical, laboratory, echocardiographic, computed tomography, and diffusion-weighted

magnetic resonance imaging (DW-MRI) data. Face-to-face assessments were conducted at admission and during the 1-year follow-up if patients returned to the hospital. For those unable to attend in person, a telephone interview was conducted. Additional details are provided in Table 1. Patients with missing values for the variables of interest were excluded from the analysis.

Preoperative Evaluation and Indications for Transfemoral Transcatheter Aortic Valve Replacement

At our institution, all patients are admitted and evaluated at least one day before the TAVR operation. The preoperative assessments were performed by a cardiac team consisting of a cardiac surgeon, cardiologist, and cardiac anaesthetist in a hybrid operating theatre. The study team retrieved the data from the preoperative assessment.

Patient Monitoring

Continuous monitoring involved taking measurements of heart rate (HR), invasive arterial blood pressure (IBP), five-lead electrocardiogram (ECG), peripheral oxygen saturation (SpO_2), and body temperature. Two external defibrillator pads were routinely placed on the chest in the event of shockable rhythms. INVOS 5100c surface pads (Covidien, Mansfield, MA) were placed on the forehead for continuous cerebral oxygen saturation (ScO_2) monitoring. The cardiac index (CI), systemic vascular resistance index (SVRI), and stroke volume variation (SVV) were measured via the ProAQT/Pulsioflex system (Pulsion Medical Systems).[25] Owing to the increased risk of heart block in CoreValve patients, a temporary pacemaker was typically inserted via the internal jugular vein into patients operated on with CoreValve TAVR devices.

Administration of General Anaesthesia or Deep Sedation

At our centre, patients who undergo TAVR can opt for GA with tracheal intubation or deep sedation on the basis of their condition and the anaesthesiologist's assessment. Anaesthesia and drugs used were in accordance with standard practice at our institution. For GA, induction was performed with propofol (1–1.5 mg/kg) at divided doses as a bolus or etomidate (0.2–0.4 mg/kg), sufentanil (0.2–0.5 μg/kg), or rocuronium (0.6 mg/kg). Maintenance was achieved with propofol and remifentanil, with additional rocuronium as needed. Intubation was performed with a single-lumen endotracheal tube, and mechanical ventilation was set at 6–8 mL/kg tidal volume and 12–14 breaths/min. End-tidal carbon dioxide ($EtCO_2$) was monitored and adjusted to maintain levels between 35–45 mmHg. Postsurgery, patients without complications received sugammadex or atropine and neostigmine to reverse muscle relaxation. For deep sedation, induction was performed with propofol (0.5–1 mg/kg) and fentanyl (50 μg), which was maintained with propofol (2–4 mg/kg/h) and dexmedetomidine (0.5 μg/kg/h), with additional fentanyl as needed. All patients received supplemental oxygen via a face mask to maintain an arterial oxygen saturation >90%.

To ensure accurate assessment of postoperative delirium, patients' records were reviewed via a protocol grounded in the Confusion Assessment Method (CAM) diagnostic criteria.[26,27] Delirium was systematically evaluated at the end of each shift by trained nurses or attending physicians, who adhered to the established local protocol and enabled the continuous monitoring of delirium symptoms and their progression.

TAVR Procedure

Following a standard protocol developed at our institution, TAVR was carried out on patients with severe symptomatic aortic stenosis who were either considered inoperable or high risk for surgical aortic valve replacement. All patients were evaluated and operated on by a multidisciplinary team of experienced cardiologists, cardiovascular surgeons, and anaesthesiologists, each of whom had previously completed a minimum of 50 procedures.

All TAVR procedures were conducted via the transfemoral approach in the cardiac catheterization laboratory. A cardiovascular surgeon prepared each patient's femoral artery via a surgical approach. Following access preparation and heparin administration for anticoagulation, the native valve was opened under rapid ventricular pacing (RVP), and the prosthetic valve was implanted. The valves utilized in the process were officially sanctioned for use and included self-expanding valves such as the Evolut R/PRO (Medtronic, USA), the ACURATE neo (Boston Scientific, USA), the Venus

Table 1 Baseline Characteristics Before IPTW for Patients with and without PIH Using the MAP Thresholds of >30% Drop from Baseline and <60 mmHg

Covariate	Total Incidence (n=643)	MAP >30% Drop from Baseline			MAP <60 mmHg		
		No Postinduction Hypotension (n=328)	Postinduction Hypotension (n=315)	SMD	No Postinduction Hypotension (n=433)	Postinduction Hypotension (n=210)	SMD
Age (years), mean (SD)	74.6 (7.1)	73.8 (7.1)	75.4 (7.0)	0.221	73.9 (7.1)	75.8 (6.9)	0.27
Male, n (%)	272 (42.3)	133 (40.5)	139 (44.1)	0.072	186 (43.0)	86 (41.0)	0.041
BMI (kg/m^2), mean (SD)	22.72 (3.46)	22.78 (3.54)	22.67 (3.38)	0.031	22.80 (3.56)	22.57 (3.25)	0.067
Smoking, n (%)	162 (25.2)	81 (24.7)	81 (25.7)	0.023	109 (25.2)	53 (25.2)	0.001
Drinking, n (%)	123 (19.1)	64 (19.5)	59(18.7)	0.02	87 (20.1)	36 (17.1)	0.076
Hypertension, n (%)	361 (56.1)	179 (54.6)	182 (57.8)	0.065	237 (54.7)	124 (59.0)	0.087
Diabetes, n (%)	125 (19.4)	54 (16.5)	71 (22.5)	0.154	73 (16.9)	52 (24.8)	0.196
Atrial fibrillation, n (%)	120 (18.7)	52 (15.9)	68 (21.6)	0.147	69 (15.9)	51 (24.3)	0.209
Peripheral vascular disease, n (%)	43 (6.7)	24 (7.3)	19 (6.0)	0.052	26 (6.0)	17 (8.1)	0.082
COPD, n (%)	62 (9.6)	31 (9.5)	31 (9.8)	0.013	37 (8.5)	25 (11.9)	0.111
Coronary heart disease, n (%)	214 (33.3)	103 (31.4)	111 (35.2)	0.081	132 (30.5)	82 (39.0)	0.181
Renal failure, n (%)	11 (1.7)	4 (1.2)	7 (2.2)	0.077	8 (1.8)	3 (1.4)	0.033
Preoperative pulmonary infection, n (%)	26 (4.0)	13 (4.0)	13 (4.1)	0.008	19 (4.4)	7 (3.3)	0.055
Previous myocardial infarction, n (%)	2 (0.3)	1 (0.3)	1 (0.3)	0.002	1 (0.2)	1 (0.5)	0.041
Preoperative hydrothorax, n (%)	24 (3.7)	13 (4.0)	11 (3.5)	0.025	16 (3.7)	8 (3.8)	0.006
Previous stroke, n (%)	38 (5.9)	20 (6.1)	18 (5.7)	0.016	22 (5.1)	16 (7.6)	0.104
History of PCI/CABG, n (%)	63 (9.8)	26 (7.9)	37 (11.7)	0.129	35 (8.1)	28 (13.3)	0.17
Preoperative ejection fraction <35%, n (%)	44 (6.8)	19 (5.8)	25 (7.9)	0.085	27 (6.2)	17 (8.1)	0.072
Preoperative mean gradient (mmHg), median [IQR]	45 [34, 63]	46 [35, 63]	45 [34, 61]	0.054	47 [37, 63]	45 [31, 58]	0.199
Preoperative maximum gradient (mmHg), median [IQR]	80 [64, 104]	80 [65, 104]	80 [62, 103]	0.006	82 [65, 105]	76 [60, 100]	0.034
Preoperative maximum velocity (m/s), median [IQR]	4.46 [4.00, 5.11]	4.50 [4.03, 5.19]	4.41 [3.92, 5.06]	0.051	4.52 [4.05, 5.19]	4.35 [3.88, 4.99]	0.048
Preoperative aortic valve area (cm^2), median [IQR]	0.70 [0.52, 0.88]	0.70 [0.54, 0.89]	0.71 [0.50, 0.88]	0.14	0.69 [0.53, 0.88]	0.72 [0.50, 0.88]	0.021
Aortic regurgitation (moderate/severe), n (%)	355 (55.2)	182 (55.5)	173 (54.9)	0.011	240 (55.4)	115 (54.8)	0.013
Mitral regurgitation (moderate/severe), n (%)	191 (29.7)	92 (28.0)	99 (31.4)	0.074	118 (27.3)	73 (34.8)	0.163
β adrenergic receptor blocker, n (%)	119 (18.5)	47 (14.3)	72 (22.9)	0.221	72 (16.6)	47 (22.4)	0.146
Aspirin, n (%)	163 (25.3)	89 (27.1)	74 (23.5)	0.084	113 (26.1)	50 (23.8)	0.053
Anticoagulant, n (%)	48 (7.5)	18 (5.5)	30 (9.5)	0.154	27 (6.2)	21 (10.0)	0.138
ACEI/ARBs, n (%)	184 (28.6)	85 (25.9)	99 (31.4)	0.122	116 (26.8)	68 (32.4)	0.123
Hypolipidaemic drug, n (%)	234 (36.4)	115 (35.1)	119 (37.8)	0.056	150 (34.6)	84 (40.0)	0.111
Diuretics, n (%)	181 (28.1)	98 (29.9)	83 (26.3)	0.079	122 (28.2)	59 (28.1)	0.002
Preoperative NYHA functional class III/IV, n (%)	480 (74.7)	231 (70.4)	249 (79.0)	0.199	315 (72.7)	165 (78.6)	0.136
STS score >7%, n (%)	114 (17.7)	49 (14.9)	65 (20.6)	0.149	65 (15.0)	49 (23.3)	0.213
Haemoglobin (g/dL), mean (SD)	124.11 (20.19)	126.25 (19.67)	121.87 (20.51)	0.218	125.12 (19.31)	122.02 (21.80)	0.15
Scr (μmol/L), median [IQR]	76.10 [62.00, 94.35]	76.90 [62.00, 90.25]	75.90 [61.90, 97.75]	0.11	75.00 [62.00, 90.00]	78.55 [62.62, 101.75]	0.077
Albumin (g/L), median [IQR]	36.50 [34.20, 38.60]	36.70 [34.68, 38.90]	36.00 [33.55, 38.40]	0.223	36.60 [34.30, 38.80]	36.10 [33.73, 38.10]	0.135
Emergency, n (%)	21 (3.3)	13 (4.0)	8 (2.5)	0.08	14 (3.2)	7 (3.3)	0.006

Valve brand, n (%)							
Self-expanding	533 (82.9)	282 (86.0)	251 (79.7)	0.167	371 (85.7)	162 (77.1)	0.221
Balloon-expandable	110 (17.1)	46 (14.0)	64 (20.3)		62 (14.3)	48 (22.9)	
Type of anaesthesia, n (%)							
GA	214 (33.3)	93 (28.4)	121 (38.4)	0.215	102 (23.6)	112 (53.3)	0.643
Deep sedation	429 (66.7)	235 (71.6)	194 (61.6)		331 (76.4)	98 (46.7)	
Duration of procedure (min), median [IQR]	100 [80, 125]	100 [80,125]	100 [80,123]	0.01	100 [80,125]	95 [77, 120]	0.083
Duration of intraoperative hypotension(min), median [IQR]	-	17 [11, 29]	21 [13, 35]	0.27	17 [11, 30]	22 [15, 34]	0.209
Total fluid (mL), median [IQR]	1500 [1000, 1500]	1500 [1000, 1500]	1500 [1000, 1500]	0.068	1500 [1000, 1500]	1500 [1000, 1500]	0.054
Blood loss (mL), median [IQR]	50 [50, 50]	50 [50, 50]	50 [50, 50]	0.008	50 [50, 50]	50 [50, 50]	0.082
Urine (mL), median [IQR]	300 [200, 500]	300 [200, 500]	400 [200, 500]	0.015	300 [200, 500]	400 [200, 500]	0.05
Contrast (mL), median [IQR]	100 [90, 120]	100 [90, 120]	100 [85, 120]	0.019	100 [90, 120]	100 [90, 120]	0.073

Abbreviations: SD, Standard deviation; IQR, Interquartile range; SMD, Standardized Mean Difference; IPTW, Inverse probability of treatment weighting; MAP, Mean arterial pressure; BMI, Body mass index; COPD, Chronic obstructive pulmonary disease; PCI, Percutaneous coronary intervention; CABG, Coronary artery bypass grafting; NYHA, New York Heart Association; STS, Society of Thoracic Surgeons; GA, General anaesthesia; Scr, Serum creatinine, ACEI, Angiotensin-Converting Enzyme Inhibitor; ARBs, Angiotensin Receptor Blockers.

https://doi.org/10.2147/CIA.S487629

A (Venus Medtech, China), the Vitaflow (MicroPort, China), and the TaurusOne (Peijia Medical, China), as well as balloon-expandable valves such as the SAPIEN 3/Ultra (Edwards Lifesciences, USA) and the Myval (Meril Life Sciences, India).

Determination of Baseline and Postinduction Blood Pressure

Four thresholds of MAP were established after reviewing published literature: 2 absolute thresholds (<65, <60 mmHg) and 2 relative thresholds (20% and 30% lower than baseline).[23] In this study, PIH thresholds were characterized mainly as a reduction in MAP exceeding 30% from the initial level and a MAP<60 mmHg. The baseline MAP was defined as the mean MAP over the 5 min period immediately before induction. The statistical analysis results for the other two thresholds are presented in the Supplementary Appendix. PIH was defined as occurring between the induction of anaesthesia and the onset of surgery, where a hypotensive event demonstrated with an invasive arterial blood monitor lasted for more than 1 minute. Given the varying thresholds used to define of hypotension in the available literature,[24,28,29] we categorized the exposure variables into three groups: no hypotension, a short duration (<10 minutes) of PIH, and a prolonged duration (≥10 minutes) of PIH. IOH was defined as occurring from the start of skin incision to the end of surgery, with the same definition of hypotension threshold as PIH. Prior to induction, the baseline blood pressure was recorded. Hypotension was typically treated with fluids, norepinephrine, phenylephrine, or epinephrine at the discretion of the anaesthetist.

Study Outcomes

The primary outcome was a composite of all-cause in-hospital mortality, stroke, AKI, and MI occurring after surgery completion. The secondary outcomes included postoperative delirium within 3 days after surgery, admission to the ICU, and new-onset postoperative atrial fibrillation. The outcomes were defined according to the Valve Academic Research Consortium-3 criteria (see Table S1). [30]

Statistical Analysis

Continuous variables are reported as the means and standard deviations for normally distributed data or as medians and percentiles for non-Gaussian distributed data. Categorical variables are presented as numbers and proportions. Univariate comparisons were conducted via the independent *t* test for normally distributed data and the Mann–Whitney test for nonnormally distributed data. The $\chi 2$ test was utilized for categorical data, with Fisher's exact test being used when the minimum cell size requirements for the $\chi 2$ test were not met.

Propensity scores formed the basis of the statistical analysis methods utilized in this study, with a focus on techniques such as inverse probability of treatment weighting (IPTW), propensity score matching (PSM), and propensity score regression (PSR). IPTW was the main statistical method used, with propensity scores being developed to address potential confounding factors by observed baseline characteristics. Propensity score methods are able to replace a multitude of baseline characteristics with just one composite score, which allows for the inclusion of a greater number of potential confounders than conventional regression methods do.[31,32] In our models, we included clinically relevant variables that were defined beforehand, as well as those potentially associated with the composite outcome. To investigate the composite outcome in patients with and without PIH, we matched participants at a 1:1 ratio on the basis of propensity scores via a greedy algorithm and nearest neighbour approach with a maximum calliper distance of 0.1.[33] This matching process was performed via the "MatchIt" package in R. We assessed equivalence between matched participants (PIH vs non-PIH groups) by testing differences in covariates through $\chi 2$ analyses and Mann–Whitney *U*-tests as needed. Standardized mean differences (SMDs) were calculated via the R package "Tableone". Once a matched dataset was obtained, we estimated the association between postinduction hypotension and the composite outcome using the sample relative risk (RR).

IPTW was used to examine the relationship between patients who developed PIH and the entire population that underwent TAVR. This population was hypothetically transitioned from having no PIH to having PIH. Patients were weighted by the inverse probability of experiencing postinduction hypotension and undergoing TAVR. The association between PIH and the composite outcome was estimated via the RR obtained via log-binomial regression. SMDs for each

covariate were calculated to determine whether there were significant differences between the two groups. When the SMD was 0.1 or less after IPTW, the confounder was considered to have no significant between-group difference.[34,35]

We employed the Holm–Bonferroni correction method to address the potential impact of multiple comparisons on our results. The Holm–Bonferroni correction adjusts significance levels to reduce the risk of type I errors while maintaining adequate statistical power. Specifically, we first sorted all *P* values in ascending order. Each P value was subsequently compared with its corresponding adjusted significance level: the smallest *P* value was compared with α/4, the second smallest with α/3, the third smallest with α/2, and the largest with α, where α was the initial significance level of 0.05. This method ensures that the overall significance level is controlled when multiple statistical tests are performed, thereby enhancing the reliability of the results.

A multivariable regression model using inverse probability weighting based on the propensity score was employed to investigate the relationship between the composite outcome and the duration of PIH. Confounders were predefined on the basis of clinical plausibility and included age, diabetes status, previous stroke, the Society of Thoracic Surgeons (STS) score, the serum ALB concentration, and type of anaesthesia. We modelled the duration of PIH as a continuous variable, while age (threshold of 85 years), the albumin level (threshold of 33 g/L), the STS score (threshold of 7%), and the type of anaesthesia (deep sedation vs GA) were treated as categorical variables. We introduced statistically significant variables ($P<0.10$ in the univariable analysis) and clinically significant variables into the model.

Results

Characteristics of the Cohort

A total of 777 patients underwent TAVR at The Second Affiliated Hospital of Zhejiang University School of Medicine during the study period. After excluding 134 patients (including 62 with transapical access, 15 admitted for resuscitation and emergency treatment, 52 with missing blood pressure data, and 5 who required open-heart surgery with cardiopulmonary bypass instead of TAVR), a final cohort of 643 patients was included in the final analysis. Patients were categorized into two groups on the basis of the presence or absence of PIH (Figure 1).

The mean age of the 643 patients was 74.6 years (SD 7.1), with males comprising 42.3% of the population. The mean body mass index (BMI) was 22.7 (SD 3.5). Among the patients, 56.1% had hypertension, 19.4% had diabetes, 18.7% had atrial fibrillation, and 33.3% had coronary heart disease. A small percentage of patients presented with histories of MI (0.3%), stroke (5.9%), or cardiovascular events (6.2%). A preoperative ejection fraction <35% was found in 6.8% of

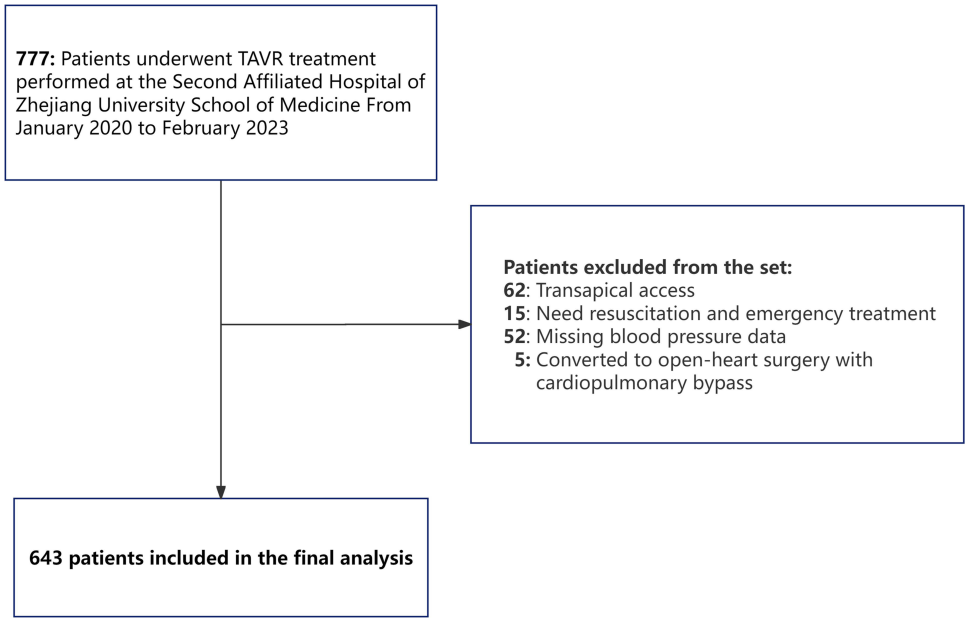

Figure 1 Flow chart.

patients, 74.7% were classified as New York Heart Association (NYHA) functional class III/IV, and 17.7% had an STS score >7%. Endotracheal intubation was used for general anaesthesia in 33.3% of the patients, whereas 66.7% of the patients received deep sedation (Table 1).

According to the thresholds used to define PIH, the incidence of PIH was 63.0%, 49.0%, 45.6%, and 32.7% in patients using the two relative thresholds (20% and 30% lower than baseline) and two absolute thresholds (<65 and <60 mmHg), respectively. The proportions of the population with a cumulative duration of PIH and the proportion of the population with a cumulative duration of IOH were shown in Figures 2, 3, S1 and S2. A total of 61 patients (9.5%) experienced a composite outcome, including all-cause in-hospital mortality in 3 patients (0.5%), stroke in 13 patients (2.0%), acute kidney injury (AKI) in 40 patients (6.2%), and myocardial infarction (MI) in 10 patients (1.6%). The secondary outcomes included postoperative delirium in 56 patients (8.7%), admission to the ICU in 53 patients (8.2%), new-onset postoperative atrial fibrillation in 27 patients (4.2%), and one-year mortality in 35 patients (5.4%).

Inverse Probability Treatment Weighting Analysis

For the primary analysis, IPTW was performed using complete data, and all 39 covariates included in the propensity analysis resulted in balanced baseline characteristics between the two groups (Tables 2 and S3). Baseline characteristics before IPTW for a MAP decrease of more than 20% from baseline and for MAP <65 mmHg were shown in Table S2. The distribution of propensity scores in the PIH and non-PIH groups were calculated before matching and after the inverse probability of treatment-weighting analysis for the two primary PIH thresholds used in this study: a relative

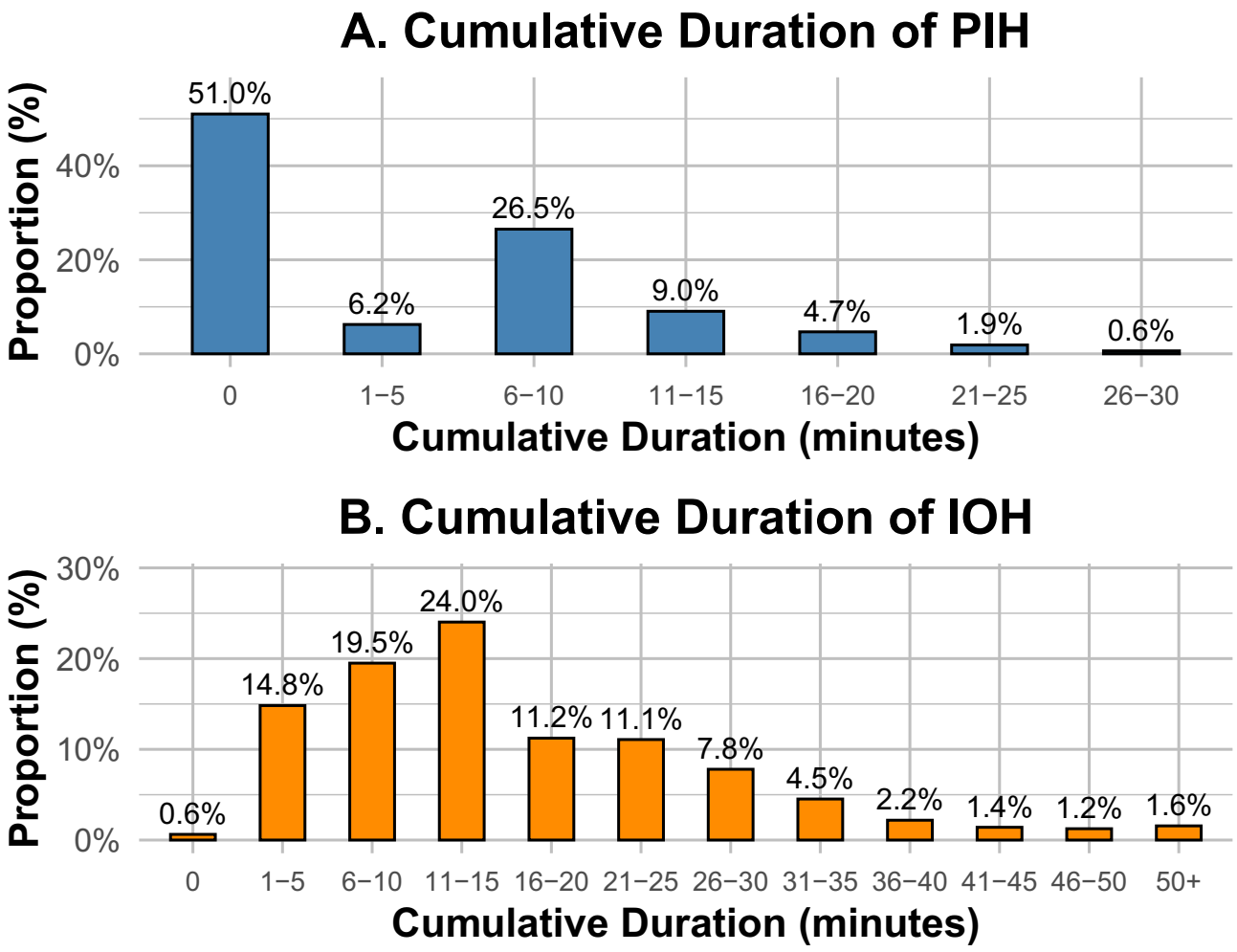

Figure 2 Cumulative duration of >30% MAP drop in patients undergoing TAVR: (**A**), postinduction hypotension; (**B**), intraoperative hypotension.

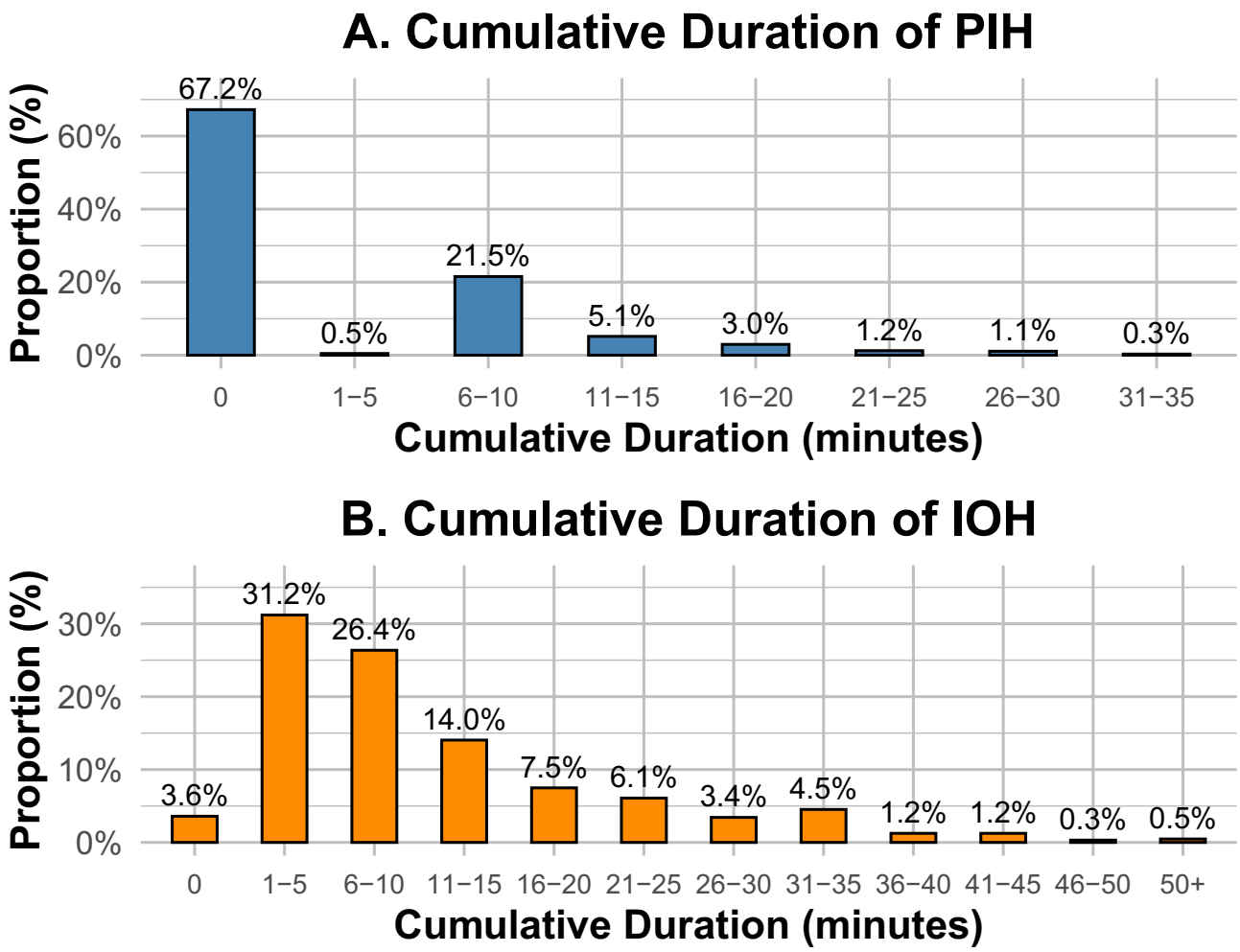

Figure 3 Cumulative duration of MAP < 60 mmHg in patients undergoing TAVR: (**A**), postinduction hypotension; (**B**), intraoperative hypotension.

threshold (MAP 30% below baseline) and an absolute threshold (MAP <60 mmHg) (Figures 4 and 5). The propensity score distribution for MAP 20% below baseline and MAP <65 mmHg was shown in Figures S3 and S4. The propensity score density plots show that, prior to matching, the PIH and non-PIH groups had significantly separated distribution curves; after matching, the curves converged, indicating successful balance of propensity scores between the groups.

According to the unadjusted analysis, patients who experienced PIH were more likely to have an adverse primary outcome than non-PIH patients. The RR for a MAP decrease of more than 30% from baseline was 2.12 [95% CI, 1.24–3.76] and the RR for a MAP less than 60 mmHg was 3.64 [95% CI, 2.13–6.35]. In the primary analysis, using IPTW on the basis of the propensity score, patients who experienced PIH were remained at higher risk of developing the composite outcome with a RR of 1.66 [95% CI, 1.14–2.46] for a MAP decrease of more than 30% from baseline and a RR of 2.47 [95% CI, 1.66–3.73] for a MAP less than 60 mmHg (Table 3).

After adjusting for IPTW, PIH correlated with stroke and AKI across all four definitions of low blood pressure, with RRs of 7.36 [95% CI, 2.72–27.40] for a MAP decrease of more than 30% from baseline, 5.22 [95% CI, 1.98–17.75] for a MAP less than 60 mmHg associated with stroke, and RRs of 1.79 [95% CI, 1.10–2.98] for a MAP decrease of more than 30% from baseline and 2.82 [95% CI, 1.73–4.79] for a MAP less than 60 mmHg associated with AKI (Table S6). After IPTW adjustment, PIH was associated with the composite outcome and its components, stroke and AKI.

The incidence of postoperative delirium (POD) was significantly greater with PIH for all four MAP thresholds, with RRs of 2.79 [95% CI, 1.39] for a MAP decrease of more than 30% from baseline, 5.89 [95% CI, 3.75–9.66] for a MAP

Table 2 Baseline Characteristics of Patients After IPTW for MAP >30% Drop from Baseline and <60 mmHg

Covariate	MAP >30% Drop from Baseline			MAP <60 mmHg		
	No Postinduction Hypotension (n=650.04)	Postinduction Hypotension (n=637.24)	SMD	No Postinduction Hypotension (n=644.1)	Postinduction Hypotension (n=634.57)	SMD
Age (years), mean (SD)	74.8 (7.4)	74.6 (7.2)	0.021	74.5 (7.2)	74.1 (7.1)	0.061
Male, n (%)	269.6 (41.5)	273.0 (42.8)	0.028	267.8 (41.6)	256.6 (40.4)	0.023
BMI (kg/m²), mean (SD)	22.70 (3.53)	22.70 (3.33)	0.001	22.75 (3.49)	22.59 (3.15)	0.048
Smoking, n (%)	161.5 (24.8)	158.0 (24.8)	0.001	164.6 (25.5)	165.0 (26.0)	0.01
Drinking, n (%)	130.0 (20.0)	128.2 (20.1)	0.003	141.5 (22.0)	128.2 (20.2)	0.044
Hypertension, n (%)	354.2 (54.9)	357.3 (55.7)	0.018	365.3 (56.7)	348.3 (54.9)	0.037
Diabetes, n (%)	125.5 (19.3)	122.1 (19.2)	0.004	132.1 (20.5)	122.2 (19.3)	0.031
Atrial fibrillation, n (%)	116.1 (17.9)	115.6 (18.1)	0.007	116.9 (18.2)	112.0 (17.6)	0.013
Peripheral vascular disease, n (%)	42.9 (6.6)	40.2 (6.3)	0.012	42.9 (6.7)	39.9 (6.3)	0.015
COPD, n (%)	55.1 (8.5)	61.1 (9.6)	0.039	60.5 (9.4)	57.5 (9.1)	0.012
Coronary heart disease, n (%)	215.7 (33.2)	210.2 (33.0)	0.004	220.2 (34.2)	215.6 (34.0)	0.004
Renal failure, n (%)	8.2 (1.3)	9.9 (1.6)	0.026	10.6 (1.6)	8.1 (1.3)	0.031
Preoperative pulmonary infection, n (%)	24.7 (3.8)	24.0 (3.8)	0.002	27.2 (4.2)	20.0 (3.2)	0.056
Previous myocardial infarction, n (%)	1.2 (0.2)	1.2 (0.2)	0.001	2.0 (0.3)	2.0 (0.3)	0.001
Preoperative hydrothorax, n (%)	26.2 (4.0)	23.2 (3.6)	0.021	24.7 (3.8)	28.6 (4.5)	0.033
Previous stroke, n (%)	35.9 (5.5)	32.0 (5.0)	0.023	34.4 (5.3)	32.0 (5.0)	0.013
History of PCI/CABG, n (%)	75.7 (11.6)	62.4 (9.8)	0.06	66.3 (10.3)	73.5 (11.6)	0.042
Preoperative ejection fraction <35%, n (%)	51.1 (7.9)	42.0 (6.6)	0.049	44.2 (6.9)	39.8 (6.3)	0.024
Preoperative mean gradient (mmHg), median [IQR]	45 [33, 62]	45 [31, 63]	0.037	45 [33, 62]	44 [31, 63]	0.09
Preoperative maximum gradient (mmHg), median [IQR]	78 [65, 101]	80 [60, 104]	0.015	78 [64, 102]	78 [55, 102]	0.055
Preoperative maximum velocity (m/s), median [IQR]	4.43 [4.03, 5.10]	4.42 [3.86, 5.09]	0.027	4.42 [4.00, 5.09]	4.40 [3.80, 5.04]	0.052
Preoperative aortic valve area (cm²), median [IQR]	0.68 [0.54, 0.88]	0.72 [0.51, 0.90]	0.034	0.70 [0.53, 0.90]	0.74 [0.50, 0.90]	0.119
Aortic regurgitation (moderate/severe), n (%)	365.6 (56.2)	363.0 (57.0)	0.014	351.0 (54.5)	359.2 (56.6)	0.042
Mitral regurgitation (moderate/severe), n (%)	193.7 (29.8)	192.6 (30.2)	0.009	188.2 (29.2)	188.5 (29.7)	0.011
β adrenergic receptor blocker, n (%)	116.6 (17.9)	116.3 (18.2)	0.008	118.2 (18.4)	121.2 (19.1)	0.019
Aspirin, n (%)	154.7 (23.8)	156.9 (24.6)	0.019	163.5 (25.4)	153.0 (24.1)	0.029
Anticoagulant, n (%)	54.4 (8.4)	50.3 (7.9)	0.017	46.2 (7.2)	48.0 (7.6)	0.015
ACEI/ARBs, n (%)	186.3 (28.7)	188.9 (29.6)	0.022	187.2 (29.1)	198.8 (31.3)	0.05
Hypolipidaemic drug, n (%)	232.6 (35.8)	225.8 (35.4)	0.007	231.2 (35.9)	231.8 (36.5)	0.013
Diuretics, n(%)	180.2 (27.7)	178.1 (28.0)	0.005	175.5 (27.2)	182.6 (28.8)	0.034
Preoperative NYHA functional class III/IV, n(%)	491.7 (75.6)	482.6 (75.7)	0.002	485.3 (75.3)	495.2 (78.0)	0.064
STS score >7% n (%)	113.7 (17.5)	116.3 (18.2)	0.019	108.9 (16.9)	102.7 (16.2)	0.00
Haemoglobin (g/dL), mean (SD)	123.89 (19.98)	123.64 (19.51)	0.013	124.07 (19.35)	124.78 (21.00)	0.035
Scr (μmol/L), median [IQR]	77.00 [63.00, 91.92]	74.07 [61.13, 94.70]	0.001	77.00 [63.95, 91.50]	76.00 [61.74, 94.90]	0.037
Albumin (g/L), median [IQR]	36.40 [34.20, 38.43]	36.50 [34.10, 38.66]	0.001	36.50 [34.20, 38.65]	36.60 [34.10, 38.40]	0.002

Emergency, n (%)	19.9 (3.1)	16.7 (2.6)	0.022	19.9 (3.1)	16.4 (2.6)	0.03
Valve brand, n (%)						
Self-expanding	543.5 (83.6)	531.0 (83.3)	0.008	531.2 (82.5)	519.3 (81.8)	0.017
Balloon-expandable	106.5 (16.4)	106.2 (16.7)		112.9 (17.5)	115.3 (18.2)	
Type of anaesthesia						
GA	225.3 (34.7)	220.8 (34.7)	<0.001	216.7 (33.6)	217.6 (34.3)	0.014
Deep sedation	424.7 (65.3)	416.4 (65.3)		427.4 (66.4)	417.0 (65.7)	
Duration of procedure (min), median [IQR]	100 [80, 125]	95 [80, 120]	0.028	100 [80, 125]	95 [75, 120]	0.048
Duration of intraoperative hypotension (min), median [IQR]	18 [12, 34]	19 [12, 32]	0.009	18 [12, 33]	21 [13, 30]	0.056
Total fluid (mL), median [IQR]	1500 [1000, 1500]	1500 [1000, 1500]	0.022	1500 [1000, 1500]	1500 [1000, 1500]	0.022
Blood loss (mL), median [IQR]	50 [50, 50]	50 [50, 50]	0.019	50 [50, 50]	50 [20, 50]	0.035
Urine (mL), median [IQR]	300 [200, 500]	400 [200, 500]	0.015	300 [200, 500]	450 [200, 500]	0.027
Contrast (mL), median [IQR]	100 [90, 120]	100 [84, 120]	0.037	100 [88, 120]	100 [90, 120]	0.024

Abbreviations: SD, Standard deviation; IQR, Interquartile range; SMD, Standardized Mean Difference; IPTW, Inverse probability of treatment weighting; MAP, Mean arterial pressure; BMI, Body mass index; COPD, Chronic obstructive pulmonary disease; PCI, Percutaneous coronary intervention; CABG, Coronary artery bypass grafting; NYHA, New York Heart Association; STS, Society of Thoracic Surgeons; GA, general anaesthesia; Scr, Serum creatinine, ACEI, Angiotensin-Converting Enzyme Inhibitor; ARBs, Angiotensin Receptor Blockers.

https://doi.org/10.2147/CIA.S487629

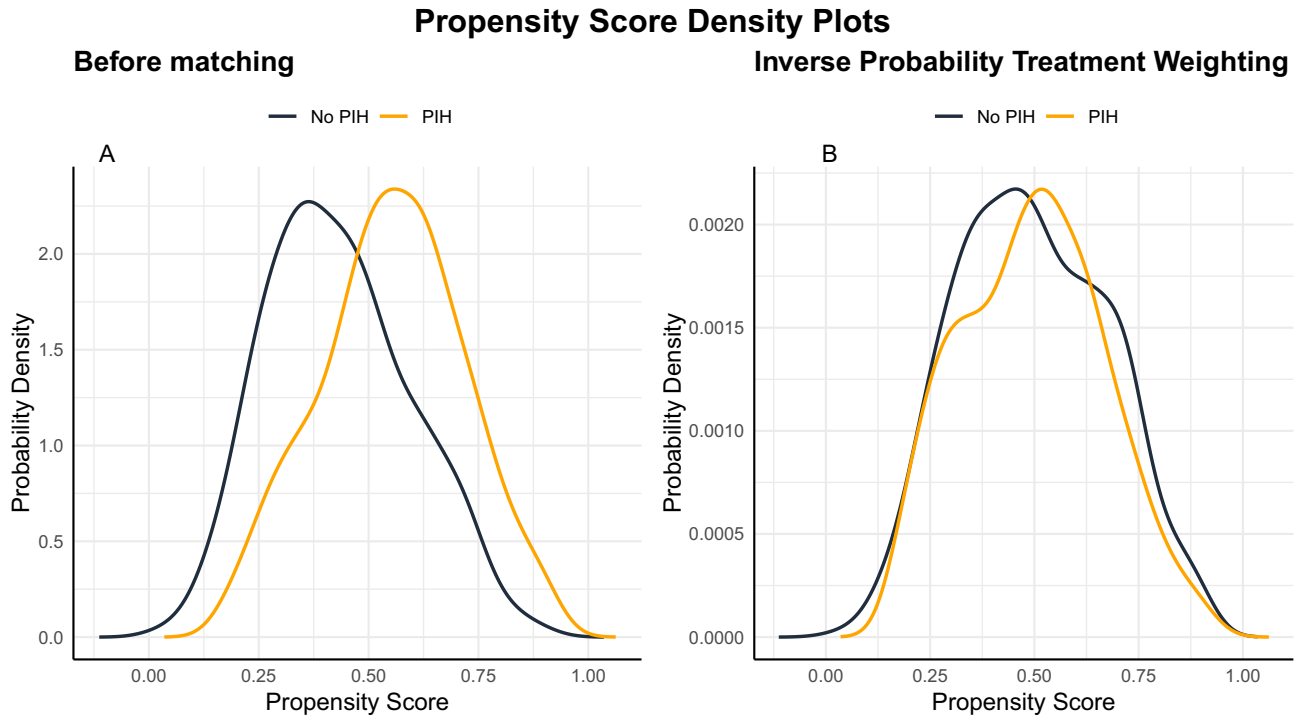

Figure 4 Propensity score distribution for a >30% MAP drop: patients with PIH vs without PIH before matching (**A**) and after inverse probability treatment weighting (**B**).

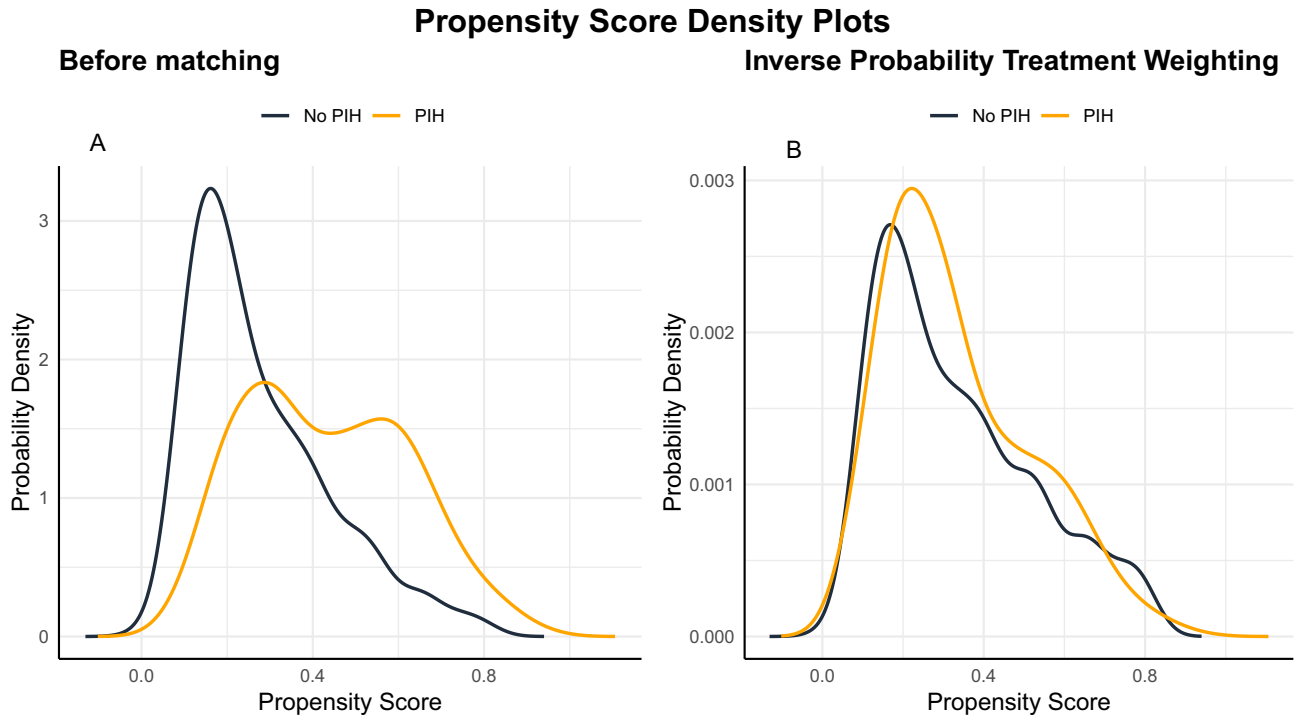

Figure 5 Propensity score distribution for MAP < 60 mmHg: patients with PIH vs without PIH before matching (**A**) and after inverse probability treatment weighting (**B**).

Table 3 Associations Between PIH and the Composite Outcome in the Crude and Propensity Score Analyses

PIH Threshold	Analysis	Relative Risk (95% CI)	*P* value
MAP >20% drop from baseline	No. of events/no. of patients at risk (%)		
	PIH, n (%)	48/405 (11.9)	—
	No PIH, n (%)	13/238 (5.5)	—
	Crude analysis	2.33 (1.23–4.39)	0.009
	Propensity-score analyses		
	With inverse probability weighting	2.02 (1.35–3.06)	<0.001
	With matching	2.03 (1.00–4.32)	0.056
	With propensity score regression	1.95 (1.03–3.92)	0.049
MAP >30% drop from baseline	No. of events/no. of patients at risk (%)		
	PIH, n (%)	40/315 (12.7)	—
	No PIH, n (%)	21/328 (6.4)	—
	Crude analysis	2.12 (1.24–3.76)	0.007
	Propensity-score analyses		
	With inverse probability weighting	1.66 (1.14–2.46)	0.01
	With matching	1.87 (1.015–3.57)	0.048
	With propensity score regression	1.62 (2.23–66.38)	0.104
MAP <65 mmHg	No. of events/no. of patients at risk (%)		
	PIH, n (%)	38/293 (13.0)	—
	No PIH, n (%)	23/350 (6.6)	—
	Crude analysis	2.11 (1.24–3.69)	0.007
	Propensity-score analyses		
	With inverse probability weighting	1.53 (1.04–2.26)	0.03
	With matching	1.92 (1.03–3.72)	0.045
	With propensity score regression	1.55 (0.87–2.78)	0.138
MAP <60 mmHg	No. of events/no. of patients at risk (%)		
	PIH, n (%)	37/210 (17.6)	—
	No PIH, n (%)	24/433 (5.5)	—
	Crude analysis	3.64 (2.13–6.35)	<0.001
	Propensity-score analyses		
	With inverse probability weighting	2.47 (1.66–3.73)	<0.001
	With matching	3.81 (1.88–8.40)	<0.001
	With propensity score regression	2.89 (1.61–5.26)	<0.001

Abbreviations: PIH, Postinduction hypotension; MAP, Mean arterial pressure.

less than 60 mmHg (Table 4). When considering the thresholds of a decrease in the MAP of more than 20% from baseline and a MAP <65 mmHg, similar trends were observed (Tables 3 and S6).

Propensity Score Matching and Propensity Score Regression

Tables S4 and S5 display the baseline characteristics before and after PSM matching, whereas Figures S9–S12 illustrate the SMD plots for both stages. The distributions of the propensity scores in the PIH and non-PIH groups is shown before and after matching are also shown (Figures S5–S8).

In the propensity score-matched bivariate analysis, participants with PIH had increased odds of the primary composite outcome (RR: 1.87 [95% CI, 1.02–3.57]) when the threshold of a MAP decrease of more than 30% from baseline was applied. A RR of 3.81 [95% CI, 1.88–8.40] was observed when a threshold of MAP less than 60 mmHg was applied. Following regression adjustment with propensity scores, patients who experienced PIH were at an increased risk of encountering the primary composite outcome when the threshold of a MAP decrease by more than 30% from baseline

Table 4 Associations Between PIH and Secondary Outcomes in the Crude and Propensity Score Analyses

Adverse Outcomes	Analysis	MAP >20% Drop from Baseline		MAP >30% Drop from Baseline		MAP <65 mmHg		MAP <60 mmHg	
		Relative Risk (95% CI)	*P* value	Relative Risk (95% CI)	*P* value	Relative Risk (95% CI)	*P* value	Relative Risk (95% CI)	*P* value
POD	No. of events/no. of patients at risk (%)								
	PIH, n (%)	44/405 (10.9)		40/315 (12.7)		40/293 (13.7)		42/210 (20.0)	
	No PIH, n (%)	12/238 (5.0)		16/328 (4.9)		16/350 (4.6)		14/433 (3.2)	
	Crude analysis	2.43 (1.17–5.07)	0.018	2.83 (1.58–5.32)	<0.001	3.30 (1.84–6.19)	<0.001	7.48 (4.07–14.53)	<0.001
	Propensity-score analyses								
	With inverse probability weighting	2.28 (1.50–3.54)	<0.001	2.79 (1.82–4.39)	<0.001	3.09 (2.00–4.89)	<0.001	5.89 (3.75–9.66)	<0.001
	With matching	2.26 (1.06–5.12)	0.04	2.51 (1.27–4.71)	0.01	2.61 (1.33–5.44)	0.007	9.04 (3.78–26.82)	<0.001
	With propensity score regression	2.16 (1.11–4.49)	0.029	2.51 (1.36–4.84)	0.004	2.82 (1.52–5.45)	0.001	6.40 (3.33–12.92)	<0.001
Admission to ICU	No. of events/no. of patients at risk (%)								
	PIH, n (%)	34/405(8.4)		30/315 (9.5)		29/293 (9.9)		28/210 (13.3)	
	No PIH, n (%)	19/238(8.0)		23/328 (7.0)		24/350 (6.9)		25/433 (5.8)	
	Crude analysis	1.06 (0.59–1.93)	0.855	1.40 (0.79–2.48)	0.249	1.49 (0.85–2.64)	0.165	2.51 (1.42–4.45)	0.001
	Propensity-score analyses								
	With inverse probability weighting	0.71 (0.48–1.02)	0.068	0.92 (0.62–1.37)	0.688	0.89 (0.60–1.33)	0.59	1.10 (0.74–1.62)	0.647
	With matching	0.92 (0.45–1.88)	0.823	1.17 (0.62–2.25)	0.624	1.12 (0.58–2.15)	0.741	1 (0.52–1.94)	1
	With propensity score regression	0.75 (0.40–1.41)	0.359	0.91 (0.50–1.68)	0.759	0.91 (0.49–1.67)	0.75	1.10 (0.57–2.08)	0.774
New-onset atrial fibrillation	No. of events/no. of patients at risk (%)								
	PIH, n (%)	20/405 (4.9)		17/315 (5.4)		14/293 (4.8)		7/210 (3.3)	
	No PIH, n (%)	7/238 (2.9)		10/328 (3.0)		13/350 (3.7)		20/433 (4.6)	
	Crude analysis	1.71 (0.71–4.12)	0.228	1.81 (0.83–4.17)	0.143	1.30 (0.60–2.85)	0.504	0.71 (0.28–1.64)	0.448
	Propensity-score analyses								
	With inverse probability weighting	1.70 (0.97–3.07)	0.07	1.88 (1.09–3.34)	0.026	1.47 (0.85–2.57)	0.169	0.61 (0.32–1.12)	0.115
	With matching	1.54 (0.54–4.68)	0.424	2.22 (0.92–5.90)	0.088	1.47 (0.62–6.63)	0.385	1 (0.31–3.25)	1
	With propensity score regression	1.76 (0.73–4.75)	0.231	1.78 (0.78–4.28)	0.909	1.33 (0.58–3.05)	0.5	0.71 (0.26–1.76)	0.484

Abbreviations: PIH, Postinduction hypotension; MAP, Mean arterial pressure; POD, Postoperative delirium; ICU, Intensive care unit.

was applied (RR: 1.87 [95% CI, 1.02–3.57]) or when MAP was below 60 mmHg (RR: 2.89 [95% CI, 1.61–5.26]) (Table 3).

After PSM and propensity score regression, a MAP below the absolute threshold of 60 mmHg following the induction was associated with a greater risk of both stroke (RR 4.89 [95% CI, 1.33–23.48]) and AKI (RR 3.27 [95% CI, 1.60–6.92]) (Table S6). Moreover, a greater risk of POD was observed in patients with PIH when the four different thresholds used to define hypotension were applied using the same statistical approach for analysis (Table 4).

The approach taken adjusted the significance levels to reduce the risk of type I errors while maintaining adequate statistical power. Using an initial significance level of 0.05, the adjusted significance levels were 0.0125 for the smallest *P* value (0.05/4), 0.0167 for the second smallest (0.05/3), 0.025 for the third smallest (0.05/2), and 0.05 for the largest. After these corrections were applied, the significant associations observed in the IPTW analyses for the thresholds of >30% below baseline ($P = 0.01 < 0.0167$) and MAP <60 mmHg ($P < 0.001 < 0.0125$) remained statistically significant. This finding indicates that, at these specific thresholds, the association between PIH and adverse clinical outcomes remained statistically significant.

Multivariate Logistic Regression

According to the thresholds used to define low blood pressure, 8.9%-17% of patients in the current study experienced prolonged PIH. The variables of age of 85, a prolonged duration of hypotension (≥10 minutes), a history of preoperative diabetes, and an STS score >7% were significantly associated with the composite outcome when the relative thresholds of greater than 20% and 30% decrease from baseline, as well as the absolute threshold of <65 mmHg were applied. When PIH was defined by the threshold of a MAP <60 mmHg, the occurrence of a composite outcome was likely even if the duration of hypotension was less than 10 minutes (Tables 5, S7–S11). The severity and duration of PIH were associated with outcomes.

Discussion

Our study revealed 1) a significant association between PIH during TAVR and increased risks of all-cause hospital in-hospital mortality, stroke, AKI, and MI across various haemodynamic thresholds via three different analyses, including propensity score analysis, IPTW, and PSM; and that 2) the risk of these outcomes was greater at lower MAP thresholds and with prolonged hypotension, especially when the MAP was less than 60 mmHg for longer than 10 minutes.

Among patients with low blood pressure, modifying the MAP threshold significantly changed the incidence of PIH. When low blood pressure was defined as a >30% decrease in MAP from baseline, 49% of patients developed hypotension. The duration of PIH varied, with most patients experiencing 6–10 minutes. In contrast, when low blood pressure was defined as a MAP <60 mmHg, the incidence of PIH was lower at 32.8%, with the highest proportion (21.5%) having cumulative PIH times of 6–10 minutes when the four different thresholds used to define hypotension were applied. The variation in incidence based on different MAP thresholds underscores the sensitivity of PIH diagnosis to the chosen definition. These results were consistent with previous studies, such as those by Salmasi et al[23] which showed that stricter MAP thresholds lead to higher reported incidences of hypotension.

Post-TAVR, the primary composite outcome rate was 9.5%, which aligns with the findings of other studies on TAVR-related complications.[4,36–39] Studies have shown that patients who experience perioperative hypotension are at increased risk for AKI because of compromised renal blood flow and increased susceptibility to ischaemic injury.[40] A study of patients undergoing elective noncardiac surgery (n=42,825) found a significant correlation between AKI and MAP values below 65 mmHg.[11] Similarly, our study revealed an association between PIH and AKI in patients undergoing TAVR. Indeed, maintaining a MAP above 60–70 mmHg may reduce the risk of kidney injury.[41] Regarding ischaemic strokes, which occur in 1.4% to 4.3% of TAVR patients, are linked to long-term disability, and are associated with increased mortality rates,[42–44] strokes that occurred during or after TAVR could result from embolized debris or blood flow instability. Individuals with impaired cerebrovascular reserve were more susceptible to stroke due to difficulty maintaining adequate brain blood flow when exposed to the cardiovascular depressant and vasodilator effects of anaesthetic agents after the induction of general anaesthesia.[45,46] Thus, maintaining adequate cerebral blood flow during anaesthesia is crucial to prevent ischaemic events.

Table 5 Associations Between PIH Duration and Composite Outcome When the Thresholds of MAP >30% Drop from Baseline and <60 mmHg Were Applied

Duration of PIH	MAP >30% Drop from Baseline				MAP <60 mmHg			
	No Composite outcome (n=582)	Composite outcome (n=61)	OR (Multivariable)	*P* value	No Composite outcome (n=582)	Composite outcome (n=61)	OR (Multivariable)	*P* value
No hypotension, n (%)	307 (52.7)	21 (34.4)	Reference	Reference	409 (70.3)	24 (39.3)	Reference	Reference
Short (<10 min) duration of hypotension, n (%)	198 (34)	12 (19.7)	0.81 (0.38-1.71)	0.575	121 (20.8)	20 (32.8)	2.13 (1.09–4.18)	0.027
Prolonged (≥10 min) duration of hypotension, n (%)	77 (13.2)	28 (45.9)	3.75 (1.92-7.35)	<0.001	52 (8.9)	17 (27.9)	4.20 (1.96–8.98)	<0.001

Abbreviations: PIH, Postinduction hypotension; MAP, Mean arterial pressure; OR, Odds Ratio.

The low incidence of mortality (0.47%) in our population likely explains the lack of a statistically significant association with mortality. Moreover, MI and PIH were not correlated, possibly because myocardial injury typically occurs in response to direct surgical manipulation.[47] Some studies show that PIH is not associated with postoperative complications, including those involving the organs.[48] This could be due to the relatively young median age of the study participants (62 years), who underwent gastrointestinal surgery and had fewer cardiovascular complications. The potential for PIH to cause adverse outcomes is mainly influenced by the patient's initial risk factors and anesthesia administration, and its clinical relevance may vary depending on how low blood pressure thresholds are defined.

Recent studies have elucidated the connection between PIH and POD following TAVR.[49,50] Promptly addressing hypotension may reduce the risk of developing POD, as hypotension can decrease cerebral perfusion, disturb brain homeostasis, and cause brain injury.[51,52] Perfusion abnormalities in the frontal and parietal lobes are specifically associated with delirium symptoms.[53]

This study found that the one-year mortality rate after TAVR was 5.4%, which agrees with previous findings. For example, a randomized controlled trial conducted by Toff et al[2] reported a post-TAVR one-year mortality rate of 4.6% among patients aged 70 years or older with severe, symptomatic aortic stenosis and moderately increased operative risk.

PIH, which is problematic for studying its impact. To overcome this, we utilized four different definitions to ensure reliability and identified that correlations between PIH and adverse outcomes remained consistent across all thresholds. Additionally, we found that the duration of hypotension influenced outcomes, with a MAP <60 mmHg for less than 10 minutes associated with an increased risk, whereas patients experiencing 20% or 30% reduction in MAP from baseline required longer durations in a hypotensive state for outcomes to be significantly impacted.

IPTW was chosen as the primary statistical method to analyze the association between PIH and adverse outcomes due to its ability to create a balanced pseudopopulation by adjusting for measured baseline covariates, thereby mimicking aspects of a randomized controlled trial.[54,55] Unlike propensity score matching, IPTW achieves smaller standardized mean differences and utilizes a larger portion of the sample, enhancing sample size efficiency and effectively reducing confounding biases. This approach is widely endorsed by high-impact medical journals for its effectiveness in minimizing confounding in observational studies.[33,56]

Hypotension during TAVR has been associated not only with postoperative complications such as stroke, MI, and AKI but may also elevate the risk of infective endocarditis (IE).[57] De Palo et al[58] emphasized that prosthetic valve IE remains a significant concern following TAVR, with in-hospital mortality rates exceeding 60% compared to patients without IE,[59,60] and a 6.55-fold higher risk of all-cause mortality within 30 days.[61] Therefore, effective management of hypotension during TAVR is crucial to minimize postoperative infection risks, particularly IE.

This study has several limitations. First, being conducted at a single center may limit the generalizability of our findings to other TAVR centers with different patient populations and protocols. Second, our analysis focused solely on MAP values during the post-induction period, excluding measurements after incision, during recovery, and in the ward, potentially overlooking important data on PIH and postoperative adverse events. Third, the retrospective design may introduce selection and information biases, as participants were not randomly selected and data may be incomplete or inaccurate, thereby limiting causal inferences due to potential confounding factors. Future prospective research is necessary to confirm whether reducing or avoiding PIH can improve postoperative outcomes, as prospective studies offer better control over confounding variables, more accurate and complete data, and the ability to test intervention strategies in randomized, controlled settings.

Conclusion

In conclusion, this retrospective cohort study found that the incidence of PIH during TAVR varied significantly depending on the thresholds used, with rates ranging from 32.7% to 63.0%. PIH was associated with increased risks of composite adverse outcomes, including all-cause in-hospital mortality, stroke, AKI, and MI. Since PIH is an easily identifiable and modifiable factor, prompt detection and treatment of PIH may reduce its incidence and severity, which in turn may positively impact patient outcomes.

Abbreviations

TAVR, Transcatheter aortic valve replacement; AKI, Acute kidney injury; MI, Myocardial infarction; IOH, Intraoperative hypotension; PIH, Postinduction hypotension; COPD, Chronic obstructive pulmonary disease; ASA, American Society of Anaesthesiology; GA, General anaesthesia; EMR, Electronic medical record; ICU, Intensive care unit; ECG, Electrocardiogram; NIBP, Noninvasive blood pressure; SPO_2, Peripheral oxygen saturation; CI, Cardiac index; SVRI, Systemic vascular resistance index; SVV, Stroke volume variation; $ETCO_2$, End-tidal carbon dioxide; CAM, Confusion assessment method; MAP, Mean arterial pressure; AS, Aortic stenosis; BMI, Body mass index; HB, Haemoglobin; ScO_2, Cerebral oxygen saturation; BIS, Bispectral index; RVP, Rapid ventricular pacing; SMDs, Standardized mean differences; DW-MRI: Diffusion-weighted magnetic resonance imaging; POD: Postoperative delirium; IPTW: Inverse probability of treatment weighting; PSM: Propensity score matching; PSR: Propensity score regression; STS: Society of Thoracic Surgeons; RR, relative risk; NYHA, New York Heart Association.

Data Sharing Statement

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgments

We extend our appreciation to the cardiovascular anesthesiology team at The Second Affiliated Hospital of Zhejiang University School of Medicine for their ongoing support, and we are thankful to the patients and staff at the Department of Heart Valve team for their assistance throughout this study.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This work was supported by the National Clinical Key Specialty Construction Project of China 2021 (grant no. 2021-LCZDZK-01 to Min Yan).

Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Thourani VH, Kodali S, Makkar RR, et al. Transcatheter aortic valve replacement versus surgical valve replacement in intermediate-risk patients: a propensity score analysis. *Lancet*. 2016;387(10034):2218–2225. doi:10.1016/s0140-6736(16)30073-3
2. Investigators TT, Fairbairn T, Kemp I, et al. Effect of transcatheter aortic valve implantation vs surgical aortic valve replacement on all-cause mortality in patients with aortic stenosis. *JAMA*. 2022;327(19):1875. doi:10.1001/jama.2022.5776
3. Avvedimento M, Tang GHL. Transcatheter aortic valve replacement (TAVR): recent updates. *Prog Cardiovasc Dis*. 2021;69:73–83. doi:10.1016/j.pcad.2021.11.003
4. Sheng SP, Strassle PD, Arora S, et al. In-hospital outcomes after transcatheter versus surgical aortic valve replacement in octogenarians. *JAHA*. 2019;8(2). doi:10.1161/jaha.118.011206
5. Jones BM, Krishnaswamy A, Tuzcu EM, et al. Matching patients with the ever-expanding range of TAVI devices. *Nat Rev Cardiol*. 2017;14(10):615–626. doi:10.1038/nrcardio.2017.82
6. Edwards FH, Cohen DJ, O'Brien SM, et al. Development and validation of a risk prediction model for in-hospital mortality after transcatheter aortic valve replacement. *JAMA Cardiol*. 2016;1(1):46. doi:10.1001/jamacardio.2015.0326
7. Makkar RR, Yoon SH, Leon MB, et al. Association between transcatheter aortic valve replacement for bicuspid vs tricuspid aortic stenosis and mortality or stroke. *JAMA*. 2019;321(22):2193. doi:10.1001/jama.2019.7108

8. Jiritano F, Serraino GF, Sorrentino S, et al. Risk of bleeding in elderly patients undergoing transcatheter aortic valve implantation or surgical aortic valve replacement. *Prosthesis*. 2024;6(1):175–185. doi:10.3390/prosthesis6010014
9. Hoz de la MA, Rangasamy V, Bastos AB, et al. Intraoperative hypotension and acute kidney injury, stroke, and mortality during and outside cardiopulmonary bypass: a retrospective observational cohort study. *Anesthesiology*. 2022;136(6). doi:10.1097/aln.0000000000004175
10. Gregory A, Stapelfeldt WH, Khanna AK, et al. Intraoperative hypotension is associated with adverse clinical outcomes after noncardiac surgery. *Anesthesia Analg*. 2020;132(6):1654–1665. doi:10.1213/ane.0000000000005250
11. Maheshwari K, Turan A, Mao G, et al. The association of hypotension during non-cardiac surgery, before and after skin incision, with postoperative acute kidney injury: a retrospective cohort analysis. *Anaesthesia*. 2018;73(10):1223–1228. doi:10.1111/anae.14416
12. Robinson BJ, Ebert TJ, O'Brien TJ, Colinco MD, Muzi M. Mechanisms whereby propofol mediates peripheral vasolidation in humans. *Anesthesiology*. 1997;86(1):64–72. doi:10.1097/00000542-199701000-00010
13. Green RS, Butler MB. Postintubation Hypotension in General Anesthesia. *J Intensive Care Med*. 2016;31(10):667–675. doi:10.1177/0885066615597198
14. Reich DL, Hossain S, Krol M, et al. Predictors of hypotension after induction of general anesthesia. *Anesthesia Analg*. 2005;101(3):622–628. doi:10.1213/01.ane.0000175214.38450.91
15. Jor O, Maca J, Koutna J, et al. Hypotension after induction of general anesthesia: occurrence, risk factors, and therapy. A prospective multicentre observational study. *J Anesth*. 2018;32(5):673–680. doi:10.1007/s00540-018-2532-6
16. Südfeld S, Brechnitz S, Wagner JY, et al. Post-induction hypotension and early intraoperative hypotension associated with general anaesthesia. *Br J Anaesth*. 2017;119(1):57–64. doi:10.1093/bja/aex127
17. Bijker JB, Persoon S, Peelen LM, et al. Intraoperative hypotension and perioperative ischemic stroke after general surgery. *Anesthesiology*. 2012;116(3):658–664. doi:10.1097/aln.0b013e3182472320
18. Monk TG, Bonsert MR, Henderson WG, et al. Association between intraoperative hypotension and hypertension and 30-day postoperative mortality in noncardiac surgery. *Surv Anesthesiol*. 2016;60(3):123–124. doi:10.1097/01.sa.0000482095.19063.e8
19. Sun LY, Wijeysundera DN, Tait GA, Scott Beattie W. Association of intraoperative hypotension with acute kidney injury after elective noncardiac surgery. *Surv Anesthesiol*. 2016;60(3):120–121. doi:10.1097/01.sa.0000482092.34310.28
20. Leon MB, Smith CR, Mack MJ, et al. Transcatheter or surgical aortic-valve replacement in intermediate-risk patients. *N Engl J Med*. 2016;374(17):1609–1620. doi:10.1056/nejmoa1514616
21. Smith CR, Leon MB, Mack MJ, et al. Transcatheter versus surgical aortic-valve replacement in high-risk patients. *N Engl J Med*. 2011;364(23):2187–2198. doi:10.1056/nejmoa1103510
22. Maheshwari K, Khanna S, Bajracharya GR, et al. A randomized trial of continuous noninvasive blood pressure monitoring during noncardiac surgery. *AnesthesiaAnalg*. 2018;127(2):424–431. doi:10.1213/ane.0000000000003482
23. Salmasi V, Maheshwari K, Yang D, et al. Relationship between intraoperative hypotension, defined by either reduction from baseline or absolute thresholds, and acute kidney and myocardial injury after noncardiac surgery. *Anesthesiology*. 2017;126(1):47–65. doi:10.1097/aln.0000000000001432
24. Wesselink EM, Kappen TH, Torn HM, Slooter AJC, van Klei WA. Intraoperative hypotension and the risk of postoperative adverse outcomes: a systematic review. *Br J Anaesth*. 2018;121(4):706–721. doi:10.1016/j.bja.2018.04.036
25. van Drumpt A, van Bommel J, Hoeks S, et al. The value of arterial pressure waveform cardiac output measurements in the radial and femoral artery in major cardiac surgery patients. *BMC Anesthesiol*. 2017;17(1). doi:10.1186/s12871-017-0334-2
26. Zou Y, Cole MG, Primeau FJ, McCusker J, Bellavance F, Laplante J. Detection and diagnosis of delirium in the elderly: psychiatrist diagnosis, confusion assessment method, or consensus diagnosis? *Int Psychogeriatr*. 1998;10(3):303–308. doi:10.1017/s1041610298005390
27. Li T, Li J, Yuan L, et al. Effect of regional vs general anesthesia on incidence of postoperative delirium in older patients undergoing hip fracture surgery. *JAMA*. 2022;327(1):50. doi:10.1001/jama.2021.22647
28. Yu Q, Qi J, Wang Y. Intraoperative hypotension and neurological outcomes. *Curr Opin Anaesthesiol*. 2020;33(5):646–650. doi:10.1097/aco.0000000000000904
29. Bijker JB, Gelb AW. Review article: the role of hypotension in perioperative stroke. *Can J Anesth*. 2012;60(2):159–167. doi:10.1007/s12630-012-9857-7
30. Généreux P, Piazza N, Alu MC, et al. Valve academic research consortium 3: updated endpoint definitions for aortic valve clinical research. *J Am Coll Cardiol*. 2021;77(21):2717–2746. doi:10.1016/j.jacc.2021.02.038
31. Williamson EJ, Forbes A. Introduction to propensity scores. *Respirology*. 2014;19(5):625–635. doi:10.1111/resp.12312
32. Brookhart MA, Schneeweiss S, Rothman KJ, Glynn RJ, Avorn J, Stürmer T. Variable Selection for Propensity Score Models. *Am J Epidemiol*. 2006;163(12):1149–1156. doi:10.1093/aje/kwj149
33. Grool AM, Aglipay M, Momoli F, et al. Association between early participation in physical activity following acute concussion and persistent postconcussive symptoms in children and adolescents. *JAMA*. 2016;316(23):2504. doi:10.1001/jama.2016.17396
34. Zhang Z, Kim HJ, Lonjon G, Zhu Y; Group written on behalf of ABDCTC. Balance diagnostics after propensity score matching. *Ann Transl Med*. 2019;7(1):16. doi:10.21037/atm.2018.12.10
35. El-Galaly A, Nielsen PT, Kappel A, Jensen SL. Reduced survival of total knee arthroplasty after previous unicompartmental knee arthroplasty compared with previous high tibial osteotomy: a propensity-score weighted mid-term cohort study based on 2133 observations from the Danish knee arthroplasty registry. *Acta Orthop*. 2020;91(2):177–183. doi:10.1080/17453674.2019.1709711
36. Liu X, Dai H, Fan J, et al. Cerebral ischemic injury after transcatheter aortic valve replacement in patients with pure aortic regurgitation. *J Zhejiang Univ Sci B*. 2023;24(6):530–538. doi:10.1631/jzus.b2200444
37. Jhaveri KD, Saratzis AN, Wanchoo R, Sarafidis PA. Endovascular aneurysm repair (EVAR)– and transcatheter aortic valve replacement (TAVR)–associated acute kidney injury. *Kidney Int*. 2017;91(6):1312–1323. doi:10.1016/j.kint.2016.11.030
38. Muntané-Carol G, Urena M, Munoz-Garcia A, et al. Late cerebrovascular events following transcatheter aortic valve replacement. *JACC*. 2020;13(7):872–881. doi:10.1016/j.jcin.2019.11.022
39. D'Onofrio A, Facchin M, Besola L, et al. Intermediate clinical and hemodynamic outcomes after transcatheter aortic valve implantation. *Ann Thorac Surg*. 2016;101(3):881–888. doi:10.1016/j.athoracsur.2015.08.032

40. Peillex M, Marchandot B, Bayer S, et al. Bedside renal doppler ultrasonography and acute kidney injury after TAVR. *JCM*. 2020;9(4):905. doi:10.3390/jcm9040905
41. Sessler DI, Bloomstone JA, Aronson S, et al. Perioperative quality initiative consensus statement on intraoperative blood pressure, risk and outcomes for elective surgery. *Br J Anaesth*. 2019;122(5):563–574. doi:10.1016/j.bja.2019.01.013
42. Levi A, Linder M, Seiffert M, et al. Management and outcome of acute ischemic stroke complicating transcatheter aortic valve replacement. *JACC*. 2022;15(18):1808–1819. doi:10.1016/j.jcin.2022.06.033
43. Kapadia S, Agarwal S, Miller DC, et al. Insights into timing, risk factors, and outcomes of stroke and transient ischemic attack after transcatheter aortic valve replacement in the partner trial (Placement of aortic transcatheter valves). *Circ*. 2016;9(9). doi:10.1161/circinterventions.115.002981
44. Auffret V, Regueiro A, Del Trigo M, et al. Predictors of early cerebrovascular events in patients with aortic stenosis undergoing transcatheter aortic valve replacement. *J Am Coll Cardiol*. 2016;68(7):673–684. doi:10.1016/j.jacc.2016.05.065
45. Singla D, Gupta B, Varshney P, Mangla M, Walikar BN, Jamir T. Role of carotid corrected flow time and peak velocity variation in predicting fluid responsiveness: a systematic review and meta-analysis. *Korean J Anesthesiol*. 2023;76(3):183–193. doi:10.4097/kja.22385
46. Reynolds MR, Grubb RL, Clarke WR, et al. Investigating the mechanisms of perioperative ischemic stroke in the carotid occlusion surgery study. *JNS*. 2013;119(4):988–995. doi:10.3171/2013.6.jns13312
47. Fairbairn TA, Steadman CD, Mather AN, et al. Assessment of valve haemodynamics, reverse ventricular remodelling and myocardial fibrosis following transcatheter aortic valve implantation compared to surgical aortic valve replacement: a cardiovascular magnetic resonance study. *Heart*. 2013;99(16):1185–1191. doi:10.1136/heartjnl-2013-303927
48. Czajka S, Putowski Z, Krzych ŁJ. Post-induction hypotension and intraoperative hypotension as potential separate risk factors for the adverse outcome: a cohort study. *J Anesth*. 2023;37(3):442–450. doi:10.1007/s00540-023-03191-7
49. Manandhar N, Naqvi S. the effect of medication prophylaxis on the incidence of delirium in elderly patients undergoing orthopedic surgery: a meta-analysis. 2018.
50. Duan W, Zhou CM, Yang JJ, et al. A long duration of intraoperative hypotension is associated with postoperative delirium occurrence following thoracic and orthopedic surgery in elderly. *J Clin Anesth*. 2023;88:111125. doi:10.1016/j.jclinane.2023.111125
51. Brown CH, Neufeld KJ, Tian J, et al. Effect of targeting mean arterial pressure during cardiopulmonary bypass by monitoring cerebral autoregulation on postsurgical delirium among older patients. *JAMA Surg*. 2019;154(9):819. doi:10.1001/jamasurg.2019.1163
52. Chaix I, Manquat E, Liu N, et al. Impact of hypotension on cerebral perfusion during general anesthesia induction: a prospective observational study in adults. *Acta Anaesthesiol Scand*. 2020;64(5):592–601. doi:10.1111/aas.13537
53. Gani H, Domi R, Kodra N, et al. The incidence of postoperative delirium in elderly patients after urologic surgery. *Med Arh*. 2013;67(1):45. doi:10.5455/medarh.2013.67.45-47
54. Pripp AH, Łosińska K, Korkosz M, Haugeberg G. A practical guide to estimating treatment effects in patients with rheumatic diseases using real-world data. *Rheumatol Int*. 2024;44(7):1265–1274. doi:10.1007/s00296-024-05597-2
55. Hernán MA, Robins JM. Using big data to emulate a target trial when a randomized trial is not available. *Am J Epidemiol*. 2016;183(8):758–764. doi:10.1093/aje/kwv254
56. Geleris J, Sun Y, Platt J, et al. Observational study of hydroxychloroquine in hospitalized patients with Covid-19. *N Engl J Med*. 2020;382(25):2411–2418. doi:10.1056/nejmoa2012410
57. Kolte D, Goldsweig A, Kennedy KF, et al. Comparison of incidence, predictors, and outcomes of early infective endocarditis after transcatheter aortic valve implantation versus surgical aortic valve replacement in the United States. *Am J Cardiol*. 2018;122(12):2112–2119. doi:10.1016/j.amjcard.2018.08.054
58. De Palo M, Scicchitano P, Malvindi PG, Paparella D. Endocarditis in patients with aortic valve prosthesis: comparison between surgical and transcatheter prosthesis. *Antibiotics*. 2021;10(1):50. doi:10.3390/antibiotics10010050
59. Mangner N, Woitek F, Haussig S, et al. Incidence, predictors, and outcome of patients developing infective endocarditis following transfemoral transcatheter aortic valve replacement. *J Am Coll Cardiol*. 2016;67(24):2907–2908. doi:10.1016/j.jacc.2016.03.588
60. Latib A, Naim C, De Bonis M, et al. TAVR-associated prosthetic valve infective endocarditis. *J Am Coll Cardiol*. 2014;64(20):2176–2178. doi:10.1016/j.jacc.2014.09.021
61. Stortecky S, Heg D, Tueller D, et al. Infective endocarditis after transcatheter aortic valve replacement. *J Am Coll Cardiol*. 2020;75(24):3020–3030. doi:10.1016/j.jacc.2020.04.044