Peri-operative application of intra-aortic balloon pumping reduced in-hospital mortality of patients with coronary artery disease and left ventricular dysfunction

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Abstract

Background: There are few reports of peri-operative application of intra-aortic balloon pumping (IABP) in patients with coronary artery disease (CAD) and different grades of left ventricular dysfunction. This study aimed to analyze the early outcomes of peri-operative application of IABP in coronary artery bypass grafting (CABG) among patients with CAD and left ventricular dysfunction, and to provide a clinical basis for the peri-operative use of IABP.

Methods: A retrospective analysis of 612 patients who received CABG in the General Hospital of People's Liberation Army between May 1995 and June 2014. Patients were assigned to an IABP or non-IABP group according to their treatments. Logistic regression analysis was performed to investigate the influence of peri-operative IABP implantation on in-hospital mortality. Further subgroup analysis was performed on patients with severe (ejection fraction [EF] $\leq$ 35%) and mild (EF = 36%–50%) left ventricular dysfunction.

Results: Out of 612 included subjects, 78 belonged to the IABP group (12.7%) and 534 to the non-IABP group. Pre-operative left ventricular EF (LVEF) and EuroSCOREII predicted mortality was higher in the IABP group compared with the non-IABP group ($P < 0.001$ in both cases), yet the two did not differ significantly in terms of post-operative in-hospital mortality ($P = 0.833$). Regression analysis showed that IABP implantation, recent myocardial infarction, critical status, non-elective operation, and post-operative ventricular fibrillation were risk factors affecting in-hospital mortality ($P < 0.01$ in all cases). Peri-operative IABP implantation was a protective factor against in-hospital mortality ($P = 0.0010$). In both the severe and mild left ventricular dysfunction subgroups, peri-operative IABP implantation also exerted a protective role against mortality ($P = 0.0303$ and $P = 0.0101$, respectively).

Conclusions: Peri-operative IABP implantation could reduce the in-hospital mortality and improve the surgical outcomes of patients with CAD with both severe and mild left ventricular dysfunction.

Keywords: Coronary artery disease; In-hospital mortality; Intra-aortic balloon pumping; Left ventricular dysfunction; Peri-operative period

Introduction

Ischemic heart disease is the primary cause of left ventricular dysfunction[1-3]: loss of cardiomyocytes following infarction, and myocardial hibernation or stunning, caused by chronic ischemia, can both result in left ventricular dysfunction. Intra-aortic balloon pumping (IABP) can increase coronary blood flow[4,5] and decrease left ventricular load,[6] thereby improving the balance of oxygen supply to the heart, reducing the area of ischemia and protecting cardiomyocytes from dying. This technique could provide critical temporary support for the functioning of the left ventricle, and help to prevent ischemic heart failure, thereby reducing peri-operative mortality associated with coronary artery bypass grafting (CABG).[7,8] Many studies[7-10] have confirmed that CABG can achieve good clinical outcomes in patients with coronary artery disease (CAD) in combination with severe left ventricular dysfunction (ejection fraction [EF] <35% or <30%). The 2011 American College of Cardiology/American Heart Association Guideline for Coronary Artery Bypass Graft Surgery, which is based on results of several randomized controlled trials (RCTs), recommended use of the IABP to reduce in-hospital mortality (IIa) for high-risk patients who have severe left main CAD, a left ventricular EF (LVEF) < 30%, or who are undergoing reoperation.[11,12] However, while there has been an agreement on peri-operative use of IABP in patients with severe left ventricular dysfunction, those with an EF that is below the normal range but over 35% are currently being unaccounted for. This patient group represents a significant proportion of clinical patients and, due to their

Access this article online

Quick Response Code:

Website: www.cmj.org

DOI: 10.1097/CM9.0000000000000178

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Chinese Medical Journal 2019;132(8)

Received: 28-10-2018 **Edited by:** Qiang Shi

reduced cardiac function, the peri-operative mortality rate of these patients often exceeds that of patients with normal heart function.[13,14] Nevertheless, there is currently no official recommendation on whether to use IABP for such patients, and these results in experience-based application of IABP being implemented in many clinical centers. Moreover, the effect of applying IABP during the peri-operative period is still controversial.[15,16] In this study, we aimed to analyze the early results of a study involving peri-operative implantation of IABP in CABG, among patients with CAD accompanied by left ventricular dysfunction. By confirming the outcomes of IABP in patients with severe left ventricular dysfunction (EF ≤ 35%), and by exploring the effect of IABP in those with mild left ventricular dysfunction (EF = 36%–50%), it was envisaged that the study would provide a more informed clinical basis for the peri-operative application of IABP.

Methods

Ethical approval

The study was conducted in accordance with the *Declaration of Helsinki* and was approved by the Institutional Review Board and Ethics Committee of the General Hospital of People's Liberation Army. Informed written consent was obtained from all patients prior to their enrollment in this study.

Patients

The study population comprised of patients receiving CABG in the General Hospital of People's Liberation Army between May 1995 and June 2014. Included patients had all been diagnosed with CAD by coronary angiography, and had a left ventricular EF ≤ 50%. Patients were assigned into an IABP or non-IABP group according to whether they had received peri-operative implantation of an IABP. Based on the severity of their left ventricular dysfunction, patients were then further divided into two subgroups: a severe group (EF ≤ 35%) and a mild group (EF = 36%–50%). EuroSCOREII predicted mortality was calculated on http://www.euroscore.org/.

Ultrasound methodology

Biplane Simpson method for left ventricular wall segmental motion abnormalities or left ventricular enlargement, and M-mode ultrasound measurement for normal or non-segmental left ventricular wall motion abnormalities.

Inclusion criteria for pre-, intra-, and post-operative use of IABP

Criteria for pre-operative IABP implantation included: triple-vessel lesion and more than 2 of the following: pre-operative left ventricular EF ≤50%; left main coronary artery stem stenosis >90%; chronic occlusion of the 3 main coronary trunks (left anterior descending [LAD], right, and circumflex coronary arteries); tight stenosis (>95%) of the proximal LAD (before the first septal or diagonal branch); proximal tight stenosis (>95%) of a dominant right coronary artery (RCA) with remote branches for the posterior wall of the left ventricle; unstable angina despite the use of intravenous nitrates and heparin, recent (<7 days prior) myocardial infarction (MI) of the anterolateral left ventricular wall; and acute ongoing angina or MI with failed percutaneous coronary intervention (PCI).

Criteria for intra- and post-operative IABP implantation included any of the following: more than one occurrence of intraoperative failure of cardiopulmonary bypass; application of high dose vasoactive drugs, including dopamine $>10\ \mu g \cdot kg^{-1} \cdot min^{-1}$; progressive decrease in blood pressure with the use of two vasoactive drugs at the same time; post-operative refractory low cardiac output syndrome (low cardiac output), with a cardiac output $<2.0\ L \cdot m^{-2} \cdot min^{-1}$, a mean arterial pressure <50 mmHg, a left atrial pressure >20 mmHg, and a central venous pressure >15 mmHg; acute myocardial infarction after surgery; malignant ventricular arrhythmia; urine volume $<0.5\ mL \cdot kg^{-1} \cdot h^{-1}$; a continuous increase in lactic acid and continuous decrease in gas oxygen saturation in arterial blood.

Statistical analysis

Data are presented as frequencies and/or percentage frequencies, or as mean ± standard deviation (SD). Between-group comparisons were performed using the Student t test, and comparison of categorical data was achieved using the Chi-squared test. Potential risk factors for in-hospital mortality were included in multivariate analyses using the logistic regression model to derive odds ratios and associated confidence intervals. Propensity score matching (PSM) was used to match the two groups. A value of $P < 0.05$ was defined as statistically significant. Statistical analysis was performed using SPSS 22.0 software (IBM, Chicago, IL, USA).

Results

Clinical characteristics

A total of 612 patients were included in the study, of whom 78 were assigned to the IABP group and 534 to the non-IABP group. The rate of application of IABP among the study population was 12.7%. Comparison of the baseline data between the IABP and non-IABP patients revealed significant differences in the frequencies of a number of the clinical criteria, as shown in Table 1. In particular, patients in the IABP group had a lower pre-operative LVEF than those in the non-IABP group (36.5% ± 6.8% *vs.* 41.2% ± 6.0%, $P < 0.001$), and their EuroSCOREII-predicted mortality was higher (5.67 ± 6.51% *vs.* 2.08 ± 1.48%, $P < 0.001$).

The subgroup with severe left ventricular dysfunction (EF ≤ 35%) comprised of 132 patients, including 34 IABP cases (25.8%) and 98 non-IABP cases. The pre-operative LVEF of IABP patients in this subgroup was lower than that of the non-IABP patients (30.0% ± 4.1% *vs.* 31.3% ± 3.7%, $P = 0.034$), and their EuroSCOREII-predicted mortality was higher (5.66 ± 7.47% *vs.* 2.57 ± 1.60%, $P < 0.001$).

The subgroup with mild left ventricular dysfunction (EF = 36%–50%) comprised of 480 patients, including 44 IABP cases (9.2%) and 436 non-IABP cases. The pre-operative

Table 1: Clinical characteristics of the patients receiving coronary artery bypass grafting.

Characteristics	IABP ($n = 78$)	Non-IABP ($n = 534$)	Statistics	P
Age (years)	60.4 ± 9.6	62.0 ± 9.1	1.44*	0.151
Sex			0.30†	0.581
Male	66 (84.61)	464 (86.89)		
Female	12 (15.38)	70 (13.10)		
Smoking	35 (44.87)	289 (54.12)	2.34†	0.126
Hypertension	41 (52.56)	281 (52.62)	0.01†	0.992
Diabetes on insulin	22 (28.20)	164 (30.71)	0.20†	0.653
Hypercholesterolemia	12 (15.39)	94 (17.60)	0.23†	0.629
Creatinine >200 μmol/L	1 (1.28)	6 (1.12)	0.01†	0.902
PVD	5 (6.41)	33 (6.18)	0.01†	0.937
CVD	6 (7.69)	77 (14.42)	2.63†	0.105
Chronic lung disease	2 (2.56)	14 (2.62)	0.01†	0.976
Recent MI	30 (38.46)	113 (21.16)	11.38†	<0.001
Aneurysm	20 (25.64)	111 (20.79)	0.95†	0.329
Pre-operative LVEF (%)	36.49 ± 6.84	41.21 ± 5.96	6.42*	<0.001
Pre-operative LVEF				
≤35%	34 (43.59)	98 (18.35)	25.63†	<0.001
36–50%	44 (56.41)	436 (81.64)	25.63†	<0.001
NYHA class III/IV	54 (69.23)	235 (44.01)	17.37†	<0.001
CCS 4	4 (5.13)	9 (1.69)	3.88†	0.049
Critical pre-operative state	23 (29.49)	11 (2.06)	97.58†	<0.001
Non-elective operation	25 (32.05)	38 (7.12)	45.82†	<0.001
Extracorporeal circulation	72 (92.31)	417 (78.09)	8.57†	0.003
Number of anastomose	2.72 ± 0.97	2.74 ± 0.91	0.23*	0.818
Isolated CABG	50 (64.10)	434 (81.27)	12.13†	<0.001
EuroSCOREII predicted mortality (%)	5.67 ± 6.51	2.08 ± 1.48	−11.01*	<0.001

Data are shown as n (%), or mean ± standard deviation. *t values. †χ^2 values. CABG: Coronary artery bypass grafting; CCS: Canadian Cardiovascular Society classification of angina; CVD: Cerebrovascular disease; EuroSCOREII: European System for Cardiac Operative Risk Evaluation II; IABP: Intra-aortic balloon pumping; LMD: Left main disease; LVEF: Left ventricular ejection fraction; NYHA: New York Heart Association; PAP: Pulmonary artery pressure; PVD: Pulmonary vascular disease; Recent MI: Myocardial infarction within the previous 30 days.

Table 2: Comparison of post-operative outcome measures among the IABP and non-IABP groups and subgroups.

Items	All patients			EF ≤35%			EF = 36%–50%		
	IABP ($n = 78$)	Non-IABP ($n = 534$)	P	IABP ($n = 34$)	Non-IABP ($n = 98$)	P	IABP ($n = 44$)	Non-IABP ($n = 436$)	P
Post-operative LVEF (%)	44.97 ± 8.85	46.27 ± 7.87	0.184	43.06 ± 9.45	42.26 ± 9.27	0.667	46.46 ± 8.17	47.17 ± 7.23	0.540
Ventilation time (min)	82.40 ± 85.94	23.42 ± 21.76	<0.001	97.52 ± 111.56	29.82 ± 23.87	<0.001	70.72 ± 57.92	21.98 ± 21.03	<0.001
ICU days	7.60 ± 6.68	4.05 ± 2.17	<0.001	8.52 ± 9.30	4.80 ± 2.51	<0.001	6.89 ± 3.52	3.88 ± 2.05	<0.001
Post-operative AF	9 (11.54)	54 (10.11)	0.699	3 (8.82)	8 (8.16)	0.904	6 (13.64)	46 (10.55)	0.530
Post-operative VF	15 (19.23)	78 (14.61)	0.288	4 (11.77)	19 (19.39)	0.313	11 (25.00)	59 (13.53)	0.040
MACCE	14 (17.95)	25 (4.68)	<0.001	3 (8.82)	11 (11.22)	0.695	11 (25.00)	14 (3.21)	<0.001
In-hospital mortality	2 (2.56)	16 (3.00)	0.833	1 (2.94)	7 (7.14)	0.376	1 (2.27)	9 (2.06)	0.926

Data are shown as n (%), or mean ± standard deviation. IABP: Intra-aortic balloon pumping; ICU: Intensive care unit; LVEF: Left ventricular ejection fraction; MACCE: Main adverse cardiovascular and cerebrovascular events; Post-operative AF: Post-operative atrial fibrillation; Post-operative VF: Post-operative ventricular fibrillation or ventricular tachycardia.

LVEF of IABP patients in this subgroup was lower than that of the non-IABP patients (41.5% ± 3.6% *vs*. 43.4% ± 3.7%, $P < 0.001$), and their EuroSCOREII-predicted mortality was higher (5.68 ± 5.75% *vs*. 1.97 ± 1.43%, $P < 0.001$).

Post-operative outcomes

The post-operative outcomes of the two groups of patients (IABP and non-IABP), and the subgroups, are shown in Table 2. Patients in the main groups exhibited significant differences in their duration of ventilation, days of

Table 3: Univariate and multivariate regression analysis of clinical factors affecting patient mortality in hospital for the entire study population.

Factors	Univariate (odds ratio [95% CI])	*P*	Multivariate (odds ratio [95% CI])	*P*
IABP implantation	0.852 (0.192, 3.779)	0.8330	0.004 (0.000, 0.112)	0.0010
Recent MI	9.280 (3.249, 26.508)	<0.0001	9.824 (2.592, 37.23)	0.0008
NYHA class III/IV	9.407 (2.144, 41.261)	0.0030	3.075 (0.571, 16.549)	0.1909
Critical status	10.107 (3.534, 28.908)	<0.0001	13.891 (2.346, 82.261)	0.0037
Pre-operative LVEF	0.935 (0.876, 0.998)	0.0426	0.948 (0.864, 1.040)	0.2616
Non-elective operation	7.840 (2.971, 20.685)	<0.0001	10.779 (2.492, 46.628)	0.0015
Ventilation time	1.008 (1.003, 1.014)	0.0021	1.004 (0.990, 1.019)	0.5438
ICU days	1.105 (1.021, 1.195)	0.0131	1.083 (0.936, 1.253)	0.2849
Post-operative VF	12.667 (4.624, 34.695)	<0.0001	9.688 (2.631, 35.666)	0.0006

Variables that were adjusted for in the analysis include: recent MI, NYHA class III/IV, critical status, preoperative LVEF, non-elective operation, ventilation time, ICU days, post-operative ventricular fibrillation. CI: Confidence interval; IABP: Intra-aortic balloon pumping; ICU: Intensive care unit; LVEF: Left ventricular ejection fraction; NYHA: New York Heart Association; Post-operative VF: Post-operative ventricular fibrillation or ventricular tachycardia; Recent MI: Myocardial infarction within the previous 30 days.

Table 4: Multivariate regression analysis of clinical factors affecting in-hospital mortality in the severe (EF $\leq$ 35%) left ventricular dysfunction subgroup ($n = 132$).

Factors	Univariate (odds ratio [95% CI])	*P*	Multivariate (odds ratio [95% CI])	*P*
IABP implantation	0.394 (0.047, 3.324)	0.3920	0.002 (0.000, 1.307)	0.0303
Sex	0.109 (0.024, 0.493)	0.0040	0.027 (0.001, 0.499)	0.0153
Recent MI	6.282 (1.408, 28.021)	0.0160	12.761 (0.711, 229.144)	0.0839
Non-elective operation	14.231 (3.044, 66.539)	0.0007	74.793 (2.235, 2503.181)	0.0160
Post-operative VF	9.815 (2.155, 44.700)	0.0032	29.748 (1.399, 632.497)	0.0296

CI: Confidence interval; EF: Ejection fraction; IABP: Intra-aortic balloon pumping; Post-operative VF: Post-operative ventricular fibrillation or ventricular tachycardia; Recent MI: Myocardial infarction within the previous 30 days.

intensive care unit (ICU) stay, and incidence of main adverse cardiac and cerebral events (MACCE) ($P < 0.001$ in all cases). The two groups did not differ in their post-operative LVEF measurements. Out of the 18 cases who died in hospital, two had been in the IABP group and 16 had been in the non-IABP group. However, the in-hospital mortality rate of the two groups did not differ significantly. There were also no significant differences in the mortality rates of IABP *vs.* non-IABP patients among the two subgroups (EF $\leq$ 35% and EF = 36%–50%).

Multivariate analysis of causes of mortality

Univariate and multivariate predictors of survival among all patients are presented in Table 3, as odds ratios and associated 95% confidence intervals. Recent MI, NYHA class III/IV, critical status, pre-operative LVEF, non-elective operation, ventilation time, duration of ICU stay, and post-operative ventricular fibrillation were all found to be related to patient survival ($P < 0.01$ in all cases). Multivariate analysis showed that IABP implantation, recent MI, critical status, non-elective operation, and post-operative ventricular fibrillation were all significantly related to patient mortality (from all causes), according to their calculated odds ratios ($P < 0.01$ in all cases); IABP implantation was protective while the other listed factors were associated with an increased risk of mortality.

Univariate and multivariate predictors of survival among the severe left ventricular dysfunction subgroup (EF $\leq$ 35%) are presented in Table 4. Multivariate analysis showed that IABP implantation, sex, nonelective operation, and post-operative ventricular fibrillation were all significantly related to patient mortality (from all causes), according to their calculated odds ratios ($P < 0.05$ in all cases). IABP implantation and sex were protective while the other listed factors were associated with an increased risk of mortality.

Univariate predictors of survival among the mild left ventricular dysfunction group (EF = 36%–50%) are presented in Table 5. Multivariate analysis showed that IABP implantation, recent MI, critical status, non-elective operation, duration of ICU stay, and post-operative ventricular fibrillation were all significantly related to patient mortality (from all causes), according to their calculated odds ratios ($P < 0.05$ in all cases); again, IABP implantation was protective while the other listed factors were associated with an increased risk of mortality.

Comparison of the IABP and non-IABP groups after PSM

PSM was used to match the IABP group to the non-IABP group, the matching variables were pre-operative variables with statistical differences, namely recent MI, NYHA class III/IV, critical pre-operative state, non-elective operation,

Table 5: Multivariate regression analysis of clinical factors affecting in-hospital mortality in the severe (EF = 36%–50%) left ventricular dysfunction subgroup (n = 480).

Factors	Univariate (odds ratio [95% CI])	*P*	Multivariate (odds ratio [95% CI])	*P*
IABP implantation	1.103 (0.137, 8.917)	0.9265	0.009 (0.000, 0.330)	0.0101
Recent MI	14.077 (2.944, 67.308)	0.0009	30.055 (2.923, 309.011)	0.0042
Critical status	23.737 (6.329, 89.023)	<0.0001	32.868 (3.981, 271.382)	0.0012
Non-elective operation	4.367 (1.089, 17.520)	0.0375	7.751 (1.026, 58.545)	0.0471
Ventilation time	1.013 (1.002, 1.024)	0.0224	0.989 (0.961, 1.018)	0.4406
ICU days	1.388 (1.203, 1.602)	<0.0001	1.532 (1.155, 2.031)	0.0030
Post-operative VF	15.074 (3.799, 59.812)	0.0001	8.296 (1.291, 53.323)	0.0258

CI: Confidence interval; EF: Ejection fraction; IABP: Intra-aortic balloon pumping; ICU: Intensive care unit; Post-operative VF: Post-operative ventricular fibrillation or ventricular tachycardia; Recent MI: Myocardial infarction within the previous 30 days.

Table 6: Comparison of the IABP and non-IABP groups after PSM (n = 128).

Characteristics	IABP (n = 64)	Non-IABP (n = 64)	Statistics	*P*
Recent MI	21 (32.81)	19 (29.69)	0.15*	0.703
Pre-operative LVEF (%)	36.73 ± 7.15	35.72 ± 7.21	−0.80†	0.426
NYHA class III/IV	40 (62.50)	38 (59.38)	0.13*	0.717
Critical pre-operative state	9 (14.06)	7 (10.94)	0.29*	0.593
Non-elective operation	14 (21.88)	12 (18.75)	0.19*	0.660
EuroSCOREII predicted mortality (%)	4.16 ± 4.17	3.03 ± 2.29	−1.90†	0.060
Ventilation time (min)	78.13 ± 78.43	27.36 ± 24.76	−4.94†	<0.001
ICU days	7.43 ± 6.88	4.51 ± 1.83	−3.28†	0.001
Post-operative VF	12 (18.75)	13 (20.31)	0.05*	0.824
Post-operative AF	7 (10.94)	3 (4.69)	1.74*	0.188
Post-operative LVEF (%)	44.80 ± 8.85	43.08 ± 9.73	−1.05†	0.298
In-hospital mortality	0	4 (6.25)	4.13*	0.042

Data are shown as n (%), or mean ± standard deviation. * χ^2 values. † t values. EuroSCOREII: European System for Cardiac Operative Risk Evaluation II; IABP: Intra-aortic balloon pumping; ICU: Intensive care unit; LVEF: Left ventricular ejection fraction; NYHA: New York Heart Association; Post-operative AF: Post-operative atrial fibrillation; Post-operative VF: Post-operative ventricular fibrillation or ventricular tachycardia; PSM: Propensity score matching; Recent MI: Myocardial infarction within the previous 30 days.

pre-operative LVEF, the range of propensity scores was controlled at 0.05. Of the 78 patients who used IABP, the final 64 patients found a control group, and a total of 128 patients were obtained, as shown in Table 6. The results showed statistically significant differences in in-hospital mortality between the two groups, IABP group and non-IABP group (0 [0.00%] *vs.* 4 [6.25%], $P = 0.042$). The in-hospital mortality IABP group is lower than non-IABP group, it is suggested that peri-operative application of IABP could reduce in-hospital mortality.

Discussion

The most significant findings of the study include that logistic regression analysis of the major factors affecting in-hospital mortality revealed that IABP implantation, recent MI, critical status, non-elective operation, and post-operative ventricular fibrillation were all independently related to in-hospital mortality, among which IABP implantation was a protective factor, indicating that its correct implementation could decrease patient mortality. Thirdly, the logistic regression analysis also found that for both subgroups of severe (EF ≤ 35%) and mild (EF = 36%–50%) left ventricular dysfunction, IABP implantation was a protective factor that reduced in-hospital mortality.

CABG is now an effective surgical treatment for CAD.[17,18] We propose that it should be considered as an active surgical treatment for patients with reduced LVEF, even those with 1 or 2 vessel lesions but who have had no severe symptoms. For patients showing angina pectoris as the major symptom, IABP should be performed as early as possible during the onset of acute myocardial ischemia, which could help to avoid severe and irreversible myocardial damage. For patients showing heart failure as the major symptom but who have stable hemodynamics, there is a risk of reperfusion injury during the CABG operation, and the early post-operative cardiac function of these patients might further deteriorate and result in hemodynamic instability. Therefore, in these patients active IABP implantation should be considered as it would assist circulation, and reduce cardiac load as well as the dependence on vasoactive drugs. Adequate IABP and sufficient assisted ventilation in these patients would effectively reduce the burden on the heart and lungs, and would facilitate the timely control of hemodynamics by using a flow-directed artery catheter and non-invasive cardiac output monitoring. In addition, dynamic bedside ultrasonography helps to evaluate cardiac function recovery, and proper use of vasoactive and antiarrhythmic drugs facilitates the maintenance of hemodynamics. All of these approaches are effective treatments for severe cardiac complications including low cardiac output syndrome and malignant arrhythmia.

Patients with CAD accompanied by left ventricular dysfunction are in an even more critical condition. Since these patients often have a history of myocardial infarction, which leads to reduced cardiac functional reserve, secondary damage of the myocardium should be avoided at all costs, and the importance of maintaining myocardial protection should overlay the entire process of peri-operative treatment. Therefore, aside from more prudent use of surgery in these patients, employing reasonable operation indications, careful surgical planning, and meticulous peri-operative management are three principles by which the survival likelihood of such patients can be improved.

According to the present study, patients in the IABP group showed poor outcomes regarding their post-operative ventilation time, number of days spent in ICU and incidence of MACCE, indicating that these patients might have a more severe disease status in comparison to the non-IABP group. However, the actual mortality rate of IABP patients was significantly lower (by 54.8%) than the EuroSCOREII-predicted value, and was also far below the values reported by similar studies (which range from 3.1% to 5.7%).[19-22] On the contrary, the actual mortality rates of the non-IABP group were not different from the prediction of EuroSCOREII. These findings suggest that the use of IABP may be beneficial in reducing in-hospital mortality.

The logistic regression analysis of major factors affecting in-hospital mortality did not identify IABP implantation as significant in a univariate analysis. Nevertheless, this factor was still included in the multivariate analysis, since it was a major factor of interest in the study. After adjusting for the effect of other confounding factors, we found that peri-operative (including pre-, intra-, and post-operative) IABP implantation is a protective factor for in-hospital mortality, indicating that it could reduce the death rate of patients in hospital. The protective function of IABP might be associated with its effects on blood flow; IABP has been shown to increase blood flow in the coronary artery and bridging vessels.[4,5,23,24] It may also be associated with an improved balance of oxygen supply and reduced left ventricular load,[6] due to the IABP providing temporary support to the left ventricle by narrowing the area of ischemia and preventing cardiac myocytes from dying. This action inhibits further deterioration of left ventricular function, and maintains the hemodynamics of patients.[25,26] In the present study, the application rate of IABP in patients with CAD with left ventricular dysfunction was 12.7%, which was higher than the frequency reported by similar studies,[27-29] which is largely a reflection of the active use of IABP in our clinical center. When a patient's condition worsens, most clinicians would hesitate to give more active treatment. However, our results indicate that, in patients with CAD in combination with left ventricular dysfunction, a better clinical outcome and lower mortality rate can be achieved if IABP is given immediately after a patient has insert indications. Although IABP implantation played an important role in lowering in-hospital mortality, based on the results of the logistic regression analysis, it also increased the incidence of MACCE by 2.4 fold, prolonged the duration of ventilation by 53.3 h, extended the length of ICU stay by 1.8 days, and decreased the incidence of post-operative ventricular fibrillation by 74% in comparison to the non-IABP patient group.

Both logistic regression and PSM are used to exclude the effects of other variables than the application of IABP. In the study, we hope to use logistic regression to obtain the independent effects of variables on in-hospital mortality and their effect values, at the same time, the effective information of obtaining samples is retained to the utmost extent. But to rule out the bias caused by the imbalance of sample size, we used PSM to match the IABP group to the non-IABP group, the results showed the in-hospital mortality of IABP group is lower than non-IABP group, it is suggested that peri-operative application of IABP could reduce in-hospital mortality of patients with CAD with left ventricular dysfunction, consistent with the conclusion of logistic regression.

Though different studies define high-risk patients differently, patients with severe left ventricular dysfunction are generally considered as warranting IABP application. The results of the present study similarly confirmed that peri-operative IABP significantly reduced in-hospital mortality of those with an EF $\leq$ 35%, and this was consistent with other studies.[8,9,11,12] The IABP patients in the EF $\leq$ 35% subgroup had an even lower EF prior to surgery, and EuroSCOREII predicted a higher mortality and more severe disease condition in these patients. However, the results revealed that the actual rate of mortality among the IABP patients was significantly lower than the predicted value as well as that reported by similar studies,[19,20,27] the IABP and non-IABP patients did not differ in terms of the rates of post-operative mortality, indicating that IABP application reduced patient death. Logistic regression analysis suggested that IABP implantation is a protective factor that decreased the in-hospital mortality of patients. Though much has been reported about the use of IABP in patients with severe left ventricular dysfunction, a clear guideline is yet to emerge on whether to use this technique in patients with lower cardiac function but whose EF is not below 35%. This group of patients mainly comprises of those with an EF between 36% and 50%, which represents a large proportion of the patients attending the clinic, but such patients could be treated differently when it comes to the peri-operative application of IABP. In our clinical center, we purposefully relaxed the inclusion criteria of pre-operative LVEF. By taking pre-operative left ventricular EF $\leq$ 50% as one of the criteria, we thereby received more patients with an EF of 36% to 50% on which to perform IABP. As for post-operative IABP implantation, patients with unstable hemodynamics and poor cardiac function were proactively administered IABP implantation where they exhibited symptoms such as poor circulation, decreased urine output, and abnormal blood gas indexes. Our findings indicated that the clinical results of this approach to IABP application were satisfactory. A total of 480 patients had an EF of 36% to 50%, and, within this, the IABP group had a higher EuroSCOREII-predicted mortality, lower LVEF values, and worse pre-operative condition. However, the post-operative mortalities of IABP and non-IABP patients did not differ from each other, and logistic regression identified IABP as a protective factor for in-hospital mortality. This indicates that the proactive use of IABP in this patient group could reduce patient deaths in hospital.

There are several limitations of the study: (1) The study assessed the overall effect of IABP pre-, intra-, and post-operation. Since only 78 patients received IABP, further dividing them into pre-operative and post-operative groups would have resulted in an even smaller sample size, which might have increased bias and reduced the reliability of the statistics. In addition, further sub-dividing the patient group would have resulted in a more scattered analysis. Instead, it is proposed that the effects of IABP individually on pre-, intra-, and post-operative phases will be further examined once more patients have been recruited to the study. (2) The single-center and retrospective nature of the study means that it carries the inherent limitations associated with a non-RCT, such as selection bias, and the quality and strength of evidence produced is thus lower than that of an RCT.

In conclusion, active peri-operative application of IABP could effectively reduce in-hospital mortality of patients with CAD with left ventricular dysfunction. In the present study, peri-operative IABP implantation prevented patient death and improved surgical outcome for both patients with CAD with severe (EF $\leq$ 35%) and mild (EF = 36%–50%) left ventricular dysfunction.

Acknowledgements

The authors thank Prof. Rong Wang for his valuable suggestions on this study.

Funding

This work was supported by a grant from the National Key R&D Program of China (No. 2016YFC1301400).

Conflicts of interest

None.

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How to cite this article: He XY, Gao CQ. Peri-operative application of intra-aortic balloon pumping reduced in-hospital mortality of patients with coronary artery disease and left ventricular dysfunction. Chin Med J 2019;132:935–942. doi: 10.1097/CM9.0000000000000178