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ORIGINAL ARTICLE

CONVENTIONAL VALVE OPERATION

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Endo-Aortic Balloon Occlusion versus Transthoracic Clamping in Minimally Invasive Mitral Valve Surgery

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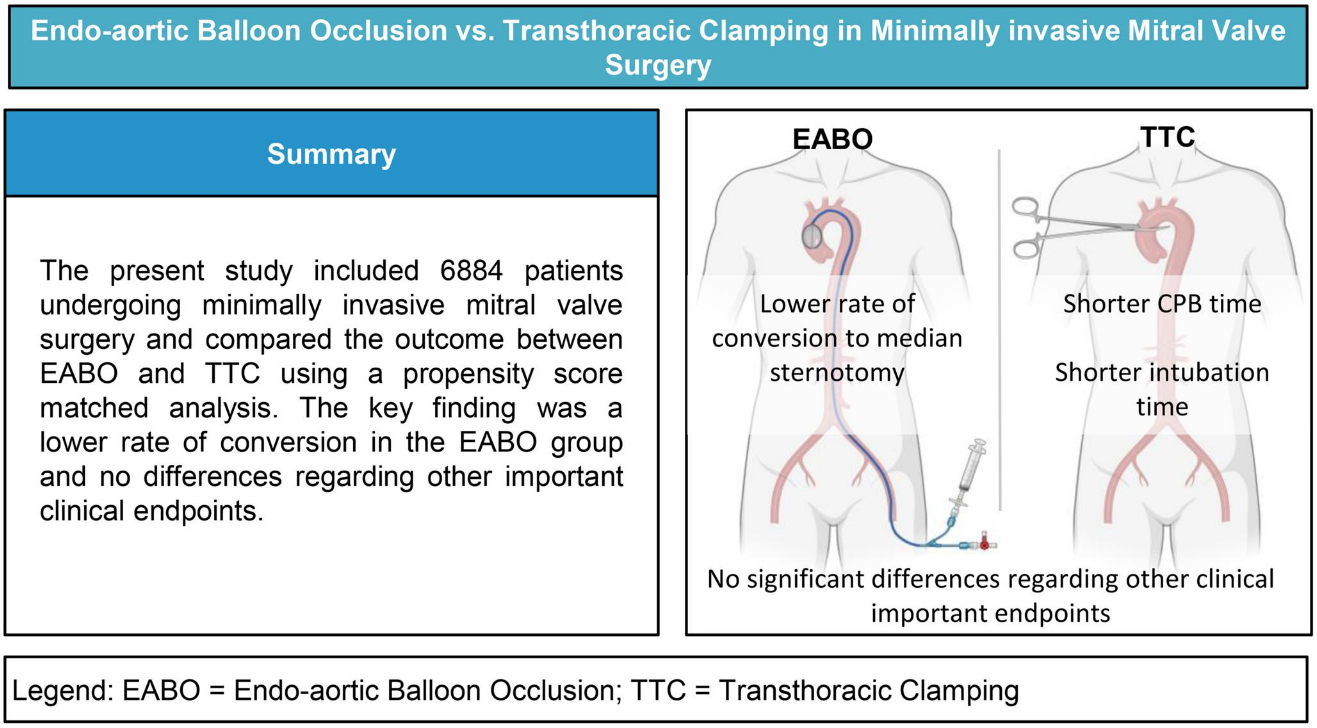
Graphical abstract



Abstract

Objectives: The present study compared the clinical outcome between endo-aortic balloon occlusion (EABO) and transthoracic clamping (TTC) in patients undergoing minimally invasive mitral valve surgery (MIMVS).

Methods: All patients from the Mini-Mitral International Registry undergoing MIMVS were primarily considered for study inclusion. One-to-one nearest neighbour propensity score matching considering clinically relevant baseline covariates. The matched cohort was investigated regarding the clinical outcome between EABO and TTC according to the end-point definitions of the Mitral Valve Academic Research Consortium.

Results: From 2015 to 2021, a total of 6884 patients were primarily included in the study. Propensity score matching resulted in a population of 733 matched pairs. Patients treated with EABO showed significantly lower rates of conversion to sternotomy (13 [1.8%] vs 34 [4.6%]; $P = .001$), longer cardiopulmonary bypass time (124 min [105-147] vs 120 min [90-148]; $P = .001$), and a longer intubation time (11.8 h [7.9-22.2] vs 10.8 h [6.4-20.0]; $P < .001$). No statistically significant differences were observed regarding postoperative mortality, stroke, bleeding requiring revision, vascular complications, intensive care unit stay, or hospital length of stay.

Conclusions: In patients undergoing MIMVS, EABO and TTC are excellent options for aortic clamping. EABO showed benefits over TTC with lower rates of conversion to full sternotomy.

Keywords: mitral valve; minimally invasive surgery; endo-aortic balloon occlusion; transthoracic clamping; clinical outcome; Mini-Mitral International Registry.

INTRODUCTION

Despite the rapidly growing field of transcatheter-based treatment options for valvular heart disease, surgery is still the treatment of choice for degenerative mitral regurgitation.[1] Following successful surgical repair, patients life expectancy can be fully restored.[2] Minimally invasive mitral valve surgery (MIMVS) with preservation of sternal integrity provides several advantages, such as improved cosmetic results, reduced postoperative pain, reduced blood loss, and a shorter length of hospital stay, leading to an overall increase of patient satisfaction.[3-8] Most minimally invasive approaches use a setup with peripheral arterial and venous cannulation to establish cardiopulmonary bypass (CPB) and either endo-aortic balloon occlusion (EABO) or transthoracic clamping (TTC) to occlude the aorta and to deliver cardioplegia.[9-11] A prospectively randomized study providing guidance for physicians regarding the use of either EABO or TTC in MIMVS is still lacking. Furthermore, most previously published studies addressing this topic are of low sample size and derive from single centres only.

Due to the limited and conflicting evidence, we aimed to perform a propensity score (PS) adjusted comparison of EABO and

TTC regarding clinically important outcome measures using data from the large Mini-Mitral International Registry (MMIR).

METHODS

Ethical statement

The study protocol was approved by the local institutional review boards of all participating centres based on the approval from the coordinating centre (n. 2020189, 30 July 2020). Patients informed consent was waived due to the retrospective study design.

End-point definitions

All clinical end-points included in the MMIR were defined previously.[12] Operative mortality [according to the EuroSCORE (ES) II] as death in the same hospital as the operation took place, prior to discharge from hospital.[13] Stroke included duration of a focal or global neurological deficit of >24 h or <24 h if available neuroimaging documents a new intracranial or subarachnoid haemorrhage or central nervous system infarction or the neurological deficit results in death. Low cardiac output included inotropic support >24 h or the use of temporary mechanical circulatory support. Bleeding included patients who required surgical re-exploration.[12] All end-points are defined according to the Mitral Valve Academic Research Consortium (MVARC) criteria.[14] The term redo is defined as any type of previous open or minimally invasive cardiac surgery procedure.

Data source and definition

The MMIR is an international registry established by a consortium of research centres to evaluate the current management and outcomes of MIMVS, with the Polytechnic University of Marche, Lancisi Cardiovascular Center (Ancona, Italy) serving as the Coordinating Centre. Participating centres provided data using the same definitions and assessment measures according to the current European Society of Cardiology or ACC/AHA/HRS Guidelines, ES II model, and MVARC end-point definitions.[1, 13,14] Further details regarding the MMIR were described previously.[12]

Patient population

At the time of this study, 7513 patients have been enrolled in the registry. Patients who underwent beating-heart or ventricular fibrillation surgery, as well as those operated on through ministernotomy, and those who received concomitant AVR were excluded. Treatment selection bias (EABO vs TTC) was addressed through PS matching. After matching, 733 well-balanced pairs were selected (**Figure 1**).

Technical considerations of EABO

In EABO, a catheter with an inflatable balloon is inserted through the femoral artery and placed in the ascending aorta under echocardiographic guidance. The aorta can be clamped from inside by administering saline solution into the balloon followed by immediate application of cardioplegia. The overall technical approach of how to use EABO is similar but in can differ in terms of its insertion (cut-down or percutaneous). A detailed tutorial of how to use EABO was published recently.[11]

Statistical analysis

Continuous variables are depicted as median with corresponding interquartile range (IQR). Categorical variables are presented as frequencies with percentages. Group differences for the unmatched cohort were tested Mann-Whitney U-Test. Proportions were compared using chi-squared test. In order to reduce the bias induced by differences in baseline characteristics, 1:1 nearest neighbour PS matching was performed. PS were estimated using logistic regression modelling with type of clamping (EABO vs TTC) as dependent variable and covariates listed in **Figure 2** as the independent variables. Patients undergoing concomitant tricuspid valve repair were matched on a 1-on-1 basis with patients undergoing MV surgery on the basis of PS, by the use of nearest-neighbour matching without replacement, and a calliper of width equal to 0.2 of the standard deviation of the logit of the PS, resulting in equal-size study cohorts. A standardized mean difference greater than 10% was considered to represent a meaningful covariate imbalance. Detailed diagnostics of the PS matching including standardized mean differences with covariate balance plot (**Table 1**, **Figure 2**) were performed. Because of missing baseline data, treatment effect sizes were estimated using the multiple imputation method. The imputation procedure was performed according to the Rubin's protocol under the assumption that missing data are missing at random. Postoperative outcomes were then compared between matched groups using standard univariate statistical tests of association. Categorical data were compared using the McNemar test. Continuous data were compared with paired *t*-test or Wilcoxon signed-rank test, as appropriate. To assess whether the effect of treatment differed by prior cardiac surgery, a logistic regression including an interaction term was performed. A 2-sided *P*-value of <.05 was considered as statistically significant. For statistical analyses, SPSS Statistics (version 27, IBM, Armonk, NY, USA) and R (Version 4.0.0, The R Foundation, Austria) were used. All data are reported in line with Statistical and data reporting guidelines of the European Journal of Cardiothoracic Surgery and the Interactive Cardiovascular and Thoracic Surgery.[15]

RESULTS

Baseline characteristics

From 2015 to 2021, a total of 6884 patients undergoing MIMVS were primarily included in the study (EABO: 1123 [16.3%] and TTC 5761 [83.7%]). Prior to PS matching, patients of the EABO group had a higher predicted risk of mortality according to the EuroSCORE II with 1.52% [0.82-3.77] compared to the TTC group with 1.23% [0.78-2.34]. After PS matching and forming 733 matched pairs, all variables were well balanced between both groups. Details regarding baseline characteristic of the unmatched and the matched cohort are presented in **Table 1**.

Comparison of operative outcome

In the matched cohort, the EABO group showed a significantly lower rate of conversion to full sternotomy compared to TTC—1.8% ($n = 13$) and 4.6% ($n = 34$); $P = .001$—as well as a longer CPB-time with 124 min [105-147] and 120 min [90-148];

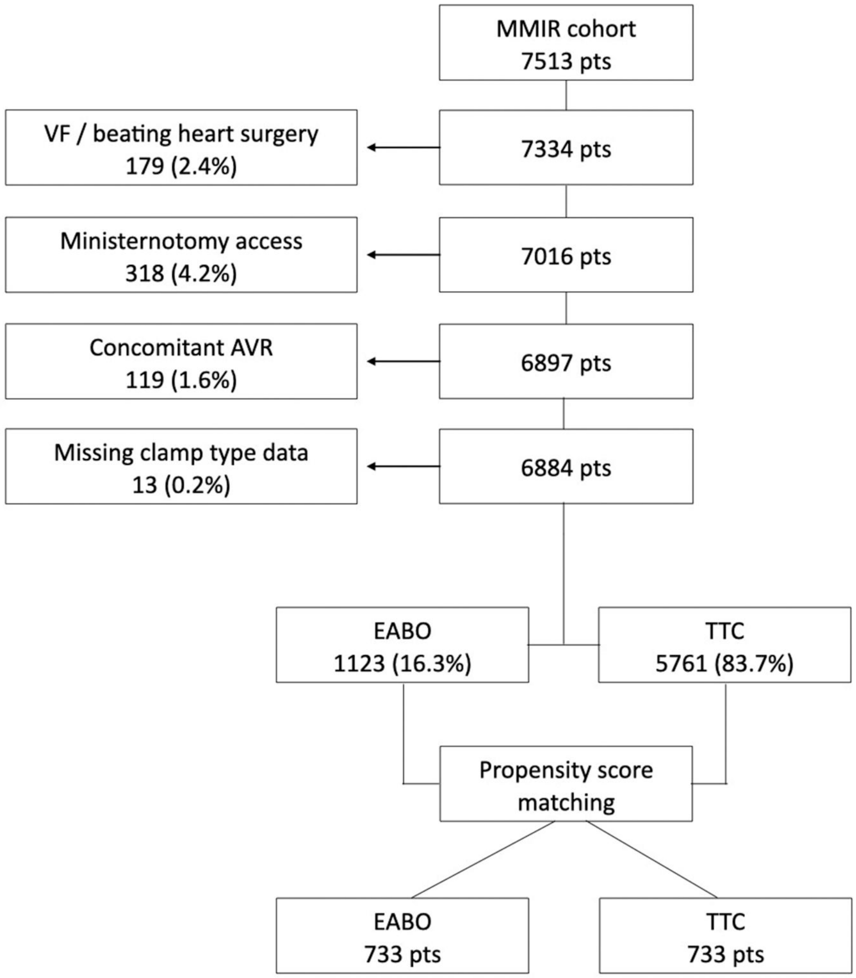


Figure 1. Flow-Chart of the Patient Population With Respective Inclusion and Exclusion Criteria. AVR, aortic valve replacement; EABO, endo-aortic balloon occlusion; MMIR, Mini Mitral International Registry; pts, patients; TTC, transthoracic clamping; VF, ventricular fibrillation

$P = .001$, respectively. Further details regarding the comparative operative outcome of both groups is demonstrated in **Table 2**.

Head to head comparison of postoperative outcome

The comparison of both groups revealed no differences in terms of in-hospital mortality (EABO: 1.2% [$n = 9$], TTC 2.5% [$n = 18$)]; $P = .100$), stroke (EABO: 1.9% [$n = 14$], TTC 1.9% [$n = 14$]; $P = 1.000$), periprocedural myocardial infarction (EABO: 1.1% [$n = 8$], TTC 0.5% [$n = 4$]; $P = .200$), major vascular complications (EABO: 0.4% [$n = 3$], TTC 1.2% [$n = 9$]; $P = .100$), and bleeding requiring revision (EABO: 6.1% [$n = 45$], TTC 5.9% [$n = 43$]; $P = .600$). Patients treated with EABO had a longer intubation time compared to the TTC group (EABO: 11.8 h [7.9-22.2], TTC: 10.8 h [6.4-20.0]; $P < .001$). More details regarding postoperative outcome are depicted in **Table 3**.

Explorative sub-analysis of outcomes for patients with previous cardiac surgery

Interaction analysis confirmed a significant treatment-by-redo interaction (OR 0.28, 95% CI 0.09-0.84; $P = .023$). In the overall study cohort, 455 patients underwent previous cardiac surgery (EABO: 204 [18.2%], TTC 251 [4.4%]; $P < .001$). The unadjusted comparison of this sub-group revealed a higher predicted operative risk for the EABO group referring to EuroSCORE II (EABO: 7.34% [3.26-12.99], TTC: 4.92% [2.63-9.19]; $P < .001$). A detailed overview of patients characteristics for the redo sub-cohort is provided in **Table S1**. The comparison of operative outcomes for the redo sub-group showed a lower rate of conversion to full sternotomy in the EABO group (0.5%, $n = 1$), compared to the TTC (6.4%, $n = 16$; $P < .001$). A detailed comparative overview of operative and in-hospital outcomes for the redo sub-cohort is provided in **Tables S2** and **S3**.

DISCUSSION

In this large, retrospective, PS matched analysis comparing the outcome between EABO and TTC in patients undergoing MIMVS, the main results can be summarized as follows: (a) EABO is associated with a lower rate of conversion to full sternotomy but longer CPB and intubation times compared to TTC; (b) both groups showed similar results in terms of other important clinical outcome measures like in-hospital mortality, stroke, myocardial infarction, and vascular complications; and

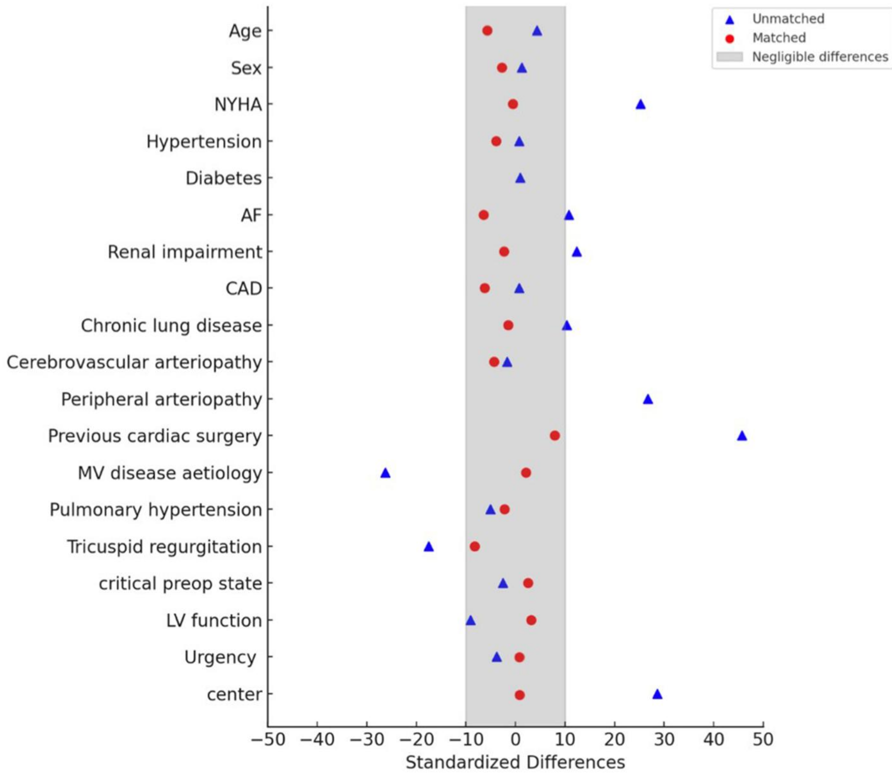


Figure 2. Covariance Balance Plot of Variables Included in the Propensity Score Matching. AF, atrial fibrillation; CAD, coronary artery disease; LV, left ventricular; NYHA, New York Heart Association

(c) the beneficial effects of EABO in terms of a lower rate of conversion to full sternotomy seem to be of particular importance for patients undergoing redo surgery.

According to recently published literature, both EABO and TTC revealed to be safe options for MIMVS. As such Balkhy et al showed no significant differences in terms of perioperative mortality or stroke between EABO and TTC and an overall low event rate for both treatment options and end-points.[16] The study was a non-randomized comparison but was based on a large propensity matched and well-balanced study cohort including 1163 matched pairs from the Society of Thoracic Surgeons (STS) Database.[16] The lack of significant between-group differences in terms of perioperative mortality and stroke was further underlined by pooled data from meta-analyses.[17,18] Our results are also in line with these data, proving EABO and TTC as safe options for MIMVS. In contrast to Balkhy et al, we found a significantly longer CPB-time in the EABO group, but considering the net median difference of only 4 min it is like that there is no influence on the clinical outcome driven by that fact.[16]

During the early era of EABO some concerns have been raised regarding an increased risk of vascular complications, especially aortic dissections.[19,20] However, in their large recently published study, Balkhy et al reported a single aortic dissection in the TTC group and none in the EABO group.[16] With a rate of less than 1% of major and minor vascular complications for EABO in the present study, concerns in this regard should be limited. It is likely that the initial higher rate of vascular complications in EABO was associated with a certain learning curve. The implementation of preoperative CT-scans as standard diagnostic most likely also contributes to a lower rate of vascular complications in MIMVS while using EABO.[15]

We also show a lower rate of conversion to sternotomy in the EABO group (1.8% vs 4.6%). These findings are also supported by a previous study, where a 3 times lower rate of conversion for EABO in MIMVS was reported.[16] It is known that EABO comes along with less aortic manipulation and the possibility to induce cardioplegia without puncturing the aorta. The handling of the aortic puncture site may be challenging in some cases and lead to an increased rate of conversion due to its complexity. However, this hypothesis is not supported by data from MMIR, since there is no significant difference regarding the reason for conversion between both groups. In contrast to our findings, the recent meta-analysis of Magouliotis et al did not show any significant differences and demonstrated a severe heterogeneity in the literature regarding potential benefits for EABO in terms of conversion to sternotomy in MIMVS.[17] The non-adjusted explorative subgroup analysis for redo-patients undergoing MIMVS showed even larger differences in the conversion rate, which is supporting EABO for redo-patients.

Clinical implications

The present study shows that EABO and TTC are safe tools for MIMVS with benefits for EABO regarding the rate of conversion to full sternotomy. The presented results should support surgeons to have EABO in their skill set, especially when performing minimally invasive redo-cases. The study is definitely strengthened by the large sample size, but still it has limitations.

Study limitations

The presented results should be interpreted under the light of the following limitations: (a) the retrospective design of the study

Table 1. Demographics

Characteristics	Overall cohort EABO (n = 1123) N (%)	Overall cohort TTC (n = 5761) N (%)	Standardized difference	*P*-value	Propensity-matched cohort EABO (n = 733) N (%)	Propensity-matched cohort TTC (n = 733) N (%)	Standardized difference	*P*-value
Age, median (IQR)	65 (55-73)	64 (55-73)	4.3	.08	65 (55-73)	66 (55-75)	−5.7	.2
Female	477 (42.5)	2395 (41.7)	1.3	.6	312 (42.6)	322 (43.9)	−2.8	.5
NYHA class III-IV	644 (57.6)	2417 (44.5)	25.2	<.001	354 (48.3)	360 (49.1)	−0.5	.4
Hypertension	397 (57.3)	3179 (57.1)	0.7	.9	382 (52.1)	395 (53.9)	−3.9	.5
Diabetes	100 (8.9)	482 (8.4)	0.9	.8	55 (7.5)	55 (7.5)	–	–
Obesity (BMI > 30)	164 (14.6)	802 (14.4)	0.9	.9	107 (14.6)	112 (15.3)	−2.4	.7
Preoperative AF	314 (39.9)	2048 (36.3)	10.7	.001	243 (33.1)	263 (35.8)	−6.5	.2
Pacemaker	30 (2.7)	180 (3.1)	−2.7	.5	12 (1.6)	23 (3.1)	−7.8	.2
Severe renal impairment (CC < 50 mL/min)	209 (18.6)	774 (14)	12.3	<.001	121 (16.5)	131 (17.9)	−2.3	.8
Dialysis	15 (1.3)	56 (1)	1.3	.3	9 (1.2)	7 (1)	2.7	.8
CAD	160 (14.2)	747 (13.4)	0.7	.5	95 (12.9)	108 (14.7)	−6.2	.7
Chronic lung disease	109 (9.7)	442 (7.7)	10.3	.03	72 (9.8)	74 (10)	−1.5	.8
Active endocarditis	46 (4.1)	200 (3.5)	3.3	.3	32 (4.3)	33 (4.5)	−1.5	.9
Cerebrovascular arteriopathy	17 (1.5)	98 (1.8)	−1.7	.6	14 (1.9)	15 (2)	−4.3	.9
Peripheral arteriopathy	64 (5.7)	112 (1.9)	26.7	<.001	24 (3.3)	25 (3.4)	−1	.9
Previous cardiac surgery	204 (18.2)	251 (4.4)	45.7	<.001	57 (7.8)	48 (6.5)	7.9	.3
Mitral valve disease aetiology			−26.3	<.001			2.1	.3
Degenerative	647 (60)	3793 (71)			479 (65.3)	460 (62.8)		
Functional	185 (17.1)	737 (13.8)			132 (18)	129 (17.6)		
Rheumatic	81 (7.5)	403 (7.6)			42 (5.7)	59 (8)		
Other	166 (15.4)	404 (7.6)			80 (10.9)	85 (11.6)		
Mitral valve insufficiency				<.001				.09
Mild	53 (4.7)	217 (3.8)	16.1		29 (4)	26 (3.5)	0.3	
Moderate	117 (10.4)	997 (17.3)			86 (11.7)	88 (12)		
Severe	934 (83.3)	4352 (75.8)			607 (82.8)	604 (82.3)		
Mitral valve stenosis *(moderate to severe)*	74 (10.7)	403 (7.2)	16	.002	59 (8)	56 (7.6)	1.1	.8
Pulmonary hypertension	379 (38.4)	2289 (41)	−5.1	.1	292 (39.8)	297 (40.5)	−2.2	.7
Tricuspid regurgitation			−17.5	<.001			−8.2	.2
Mild	281 (25.5)	1513 (26.6)			240 (32.7)	256 (34.9)		
Moderate	95 (8.6)	1305 (22.9)			71 (9.7)	81 (11)		
Severe	104 (9.4)	281 (4.9)			51 (6.9)	56 (7.6)		
Critical preoperative state	26 (2.3)	155 (2.8)	−2.6	.4	13 (1.8)	9 (1.2)	2.5	.6
LV function			−9.1	.05			3.2	.1
LVEF >50%	912 (81.9)	4683 (82.6)			604 (82.4)	597 (81.3)		
LVEF 31-50%	167 (15)	881 (15.5)			109 (14.9)	123 (16.8)		
LVEF 21-30%	32 (2.9)	92 (1.6)			19 (2.6)	11 (1.5)		
LVEF ≤20%	2 (0.2)	13 (0.2)			1 (0.1)	3 (0.4)		
Urgency	64 (5.7)	375 (6.5)	−3.8	.4	30 (4.1)	27 (3.7)	1.6	.6
EuroSCORE II (%), median (IQR)	1.52 (0.82-3.77)	1.23 (0.78-2.34)	44.4	<.001	1.22 (0.78-2.51)	1.17 (0.75-2.58)	1.4	.2

Abbreviations: EABO, endo-aortic balloon occlusion; TTC, transthoracic clamping; NYHA, New York Heart Association; BMI: body mass index; AF, atrial fibrillation; CAD, coronary artery disease; LV, left ventricular; LVEF, left ventricular ejection fraction; IQR:interquartile range.

Table 2. Operative Data

Characteristics	Overall Cohort EABO (n = 1123) N (%)	TTC (n = 5761) N (%)	*P*-value	Propensity-Matched Cohort EABO (n = 733) N (%)	TTC (n = 733) N (%)	*P*-value
Surgical approach			<.001			<.001
Direct vision	3 (0.3)	1746 (30.1)		3 (0.4)	12 (1.6)	
Video-assisted	330 (29.4)	2620 (45.5)		262 (35.7)	546 (74.5)	
Totally endoscopic	786 (70.1)	1337 (23.2)		466 (63.6)	175 (23.9)	
Robotic	2 (0.2)	54 (0.9)		2 (0.3)	–	
Surgical access			<.001			<.001
Anterolateral	988 (88)	4321 (75)		602 (82.1)	715 (97.5)	
Transaxillary	3 (0.3)	915 (15.9)		3 (0.4)	2 (0.3)	
Periareolar	132 (11.8)	525 (9.1)		128 (17.5)	16 (2.2)	
Conversion to full sternotomy	13 (1.2)	105 (1.8)	.1	13 (1.8)	34 (4.6)	.001
Causes of conversion			.1			.2
Poor exposure	–	12 (0.2)		–	4 (0.5)	
Bleeding	7 (0.6)	28 (0.5)		7 (1)	9 (1.2)	
Vascular complications	3 (0.3)	12 (0.2)		3 (0.4)	3 (0.4)	
Pleura adhesion	–	22 (0.4)			7 (1)	
Other	3 (0.3)	20 (0.4)		3 (0.4)	11 (1.5)	
Arterial cannulation site			.002			.001
Femoral artery	1109 (98.8)	5437 (96.7)		723 (98.6)	693 (94.5)	
Axillary artery	10 (0.9)	112 (2)		9 (1.2)	29 (4)	
Ascending aorta	1 (0.1)	32 (0.6)		–	9 (1.2)	
Other	3 (0.3)	43 (0.8)		1 (0.1)	2 (0.3)	
Cardioplegia type			<.001			.1
Blood	363 (32.4)	2264 (39.6)		354 (48.3)	391 (53.3)	
Crystalloid	756 (67.6)	3456 (60.5)		379 (51.7)	342 (46.7)	
Type of Surgery			<.001			.4
Mitral valve repair	831 (74.1)	4419 (76.7)		565 (77.1)	554 (75.6)	
Mitral valve replacement	287 (25.6)	1261 (21.9)		165 (22.5)	173 (23.6)	
Replacement due to unsuccessful repair	4 (0.4)	81 (1.4)		3 (0.4)	6 (0.8)	
Concomitant procedures						
Tricuspid surgery	133 (11.8)	976 (20)	<.001	71 (9.7)	79 (10.8)	.5
AF surgery	295 (26.3)	972 (16.9)	<.001	191 (26)	187 (25.5)	.7
LAA closure	84 (7.5)	847 (15.4)	<.001	36 (4.9)	47 (6.4)	.5
Repeated x-Clamping	16 (1.4)	138 (2.5)	.03	13 (1.8)	21 (2.9)	.1
CPB time (min), median IQR	130 (110-160)	134 (105-174)	.2	124 (105-147)	120 (90-148)	.001
X-clamp time (min) median IQR	89 (70-111)	82 (61-107)	<.001	84 (65-104)	82 (62-100)	.08

Abbreviations: EABO, endo-aortic balloon occlusion; TTC, transthoracic clamping; AF: atrial fibrillation; IQR: interquartile range; LAA, Left atrial appendage; CPB: cardiopulmonary bypass.

Table 3. In-Hospital Results

Characteristics	Overall cohort			Propensity-matched cohort		
	EABO (n = 1123) N (%)	TTC (n = 5761) N (%)	*P*-value	EABO (n = 733) N (%)	TTC (n = 733) N (%)	*P*-value
In-hospital mortality	21 (1.9)	89 (1.6)	.6	9 (1.2)	18 (2.5)	.1
Stroke	18 (1.6)	67 (1.2)	.2	14 (1.9)	14 (1.9)	1
Delirium	32 (4.6)	363 (6.7)	.03	32 (4.4)	32 (4.4)	1
Intubation time (h), median (IQR)	10 (7-15)	7 (5-12)	<.001	11.8 (7.9-22.2)	10.8 (6.4-20)	<.001
Bleeding (requiring revision)	68 (6.1)	317 (5.8)	.5	45 (6.1)	43 (5.9)	.6
Transfusions (unit), median (IQR)	0 (0-2)	0 (0-1)	.9	0 (0-2)	0 (0-2)	.8
New onset AF	123 (17.9)	855 (15.2)	.07	113 (15.4)	120 (16.3)	.6
Myocardial infarction			.04			.2
Periprocedural (≤48 h)	14 (1.2)	37 (0.6)		8 (1.1)	4 (0.5)	
Spontaneous (>48 h)	–	7 (0.1)		–	2 (0.3)	
Low cardiac output	16 (1.4)	227 (4)	<.001	8 (1.1)	16 (2.2)	.09
Dialysis	16 (2.3)	79 (1.5)	.1	11 (1.5)	14 (1.9)	.7
Vascular complications			.01			.1
Major	4 (0.4)	83 (1.5)		3 (0.4)	9 (1.2)	
Minor	9 (1)	32 (0.6)		5 (0.7)	4 (0.5)	
ICU stay (h), median (IQR)	24 (20-48)	24 (20-48)	.05	24 (20-64)	24 (20-60)	.1
Hospital stay (days), median (IQR)	8 (6-11)	8 (6-12)	.5	7 (6-11)	7.5 (6-11)	.7

Abbreviations: EABO, endo-aortic balloon occlusion; TTC, transthoracic clamping; AF: atrial fibrillation, IQR: interquartile range.

and the fact that balance between groups was achieved using PS is a weakness compared to a prospective randomized study design; (b) due to the fact that all procedures were performed by multiple surgeons from different centres over a long period of time, a certain operator and institution related bias cannot be precluded, especially considering the fact that in some centres EABO was not available or not used regularly; (c) the follow-up time is limited to a short term but still comparable to recently published literature[16]; (d) as for all observational studies, we assume that unmeasured confounders and missing values are randomly, which may not necessarily be the case; (e) considering the fact that most surgeons have an individual preference regarding the use of either EABO or TTC, the mentioned results may also be a comparison between surgeons, which is also supported by the differences regarding access between the 2 groups (periareolar vs regular thoracotomy); (f) the presented results should be interpreted under the light that after PS matching, only a small proportion of patients from the overall population was considered for the analysis, which may have a biasing effect; (g) due to the high sample size of the study all results should be interpreted with caution regarding statistical significance and clinical relevance (eg, ventilation time and CPB-time); (h) the MMIR consists of data from multiple centres, and even though all data were checked according to their validity and with high standards, certain differences in data quality among different centres might be present

CONCLUSION

In patients undergoing MIMVS, EABO and TTC are both excellent options with similar clinical outcomes. The use of EABO is associated with a lower rate of conversion and higher technical success but longer CPB-times compared to TTC. These facts might be of particular importance for patients undergoing surgery in a redo setting. Further prospective randomized trials are needed to strengthen the level of evidence.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

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CONFLICTS OF INTEREST

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DATA AVAILABILITY

All data underlying this article are available in the article and in the supplementary material file. Further requests regarding raw data of source codes for the analysis can be made to the corresponding author.

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