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Research Article

Benefits of On-X Mitral Valve Replacement in Cases of Infective Endocarditis

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Purpose. Mitral valve replacement (MVR) is necessary in cases of severe infective endocarditis (IE). Because the On-X valve is expected to be effective in reducing prosthesis-associated turbulent blood flow, we investigated the hemodynamic efficacy of the On-X valve when used for MVR in cases of mitral valve IE. *Methods*. We compared postoperative outcomes between two groups of patients who underwent MVR for IE: 13 given an On-X valve and 27 given an SJM valve. *Results*. There were no in-hospital deaths. Late death occurred in 6 cases, all in the SJM group ($P = 0.1520$). The incidence of late postoperative atrial fibrillation was relatively low in the On-X group (1 case vs. 10 cases, $P = 0.068$). Univariate analysis showed an association between the effective orifice area and postoperative atrial fibrillation. The effective orifice area and indexed effective orifice area were significantly larger in the On-X group at $2.8 \pm 0.7\,cm^2$ vs. $2.2 \pm 0.5\,cm^2$ ($P = 0.007$) and $1.8 \pm 0.5\,cm^2/m^2$ vs. $1.4 \pm 0.4\,cm^2$ ($P = 0.003$), respectively. *Conclusions*. The suggested reduction in left atrial load attributed to the use of the On-X valve in MVR for IE may reduce the incidence of postoperative atrial fibrillation.

1. Introduction

Mitral valve repair is considered the ideal treatment for degenerative mitral regurgitation (MR), and improved techniques have made repair of complex valve defects possible, even in cases of infective endocarditis (IE), a life-threatening disease for which mortality rates are high [1]. However, there are concerns about the durability of complex mitral valve repair, particularly when performed on infected tissue in cases of active IE [2]. Therefore, mitral valve replacement (MVR) remains an important treatment, especially in cases of severe valvular destruction and one or more large vegetations [3, 4]. In recent years at our institution, MVR has been performed in some cases of degenerative MR but mainly in cases of IE causing significant mitral valve destruction, i.e., cases for which valve repair would have proved difficult or even impossible.

The St Jude Medical (SJM) mechanical heart valve (St Jude Medical, Minneapolis, MN, USA) and the On-X mechanical bileaflet valve (On-X Life Technologies Inc., Austin, TX, USA) are the leading mechanical prostheses used for MVR. The SJM valve has been considered the most reliable prosthetic valve due to its low-profile design, long-term durability, and excellent hemodynamic performance [5, 6]. The On-X valve is a second-generation mechanical prosthesis with unique design features [6–10], and it is reported to reduce the incidence of thromboembolism [7, 11–15], bleeding events [7, 12–15], and chronic hemolysis [13, 14, 16] and to improve hemodynamics [6–9, 12–14, 17, 18]. We have expected the On-X valve to minimize tissue interference and pannus overgrowth and have used it in recent years when performing MVR for IE. Although the On-X valve is associated with relatively few pathological events (e.g., thromboembolism and bleeding) on account of the improved hemodynamics, minimal data are available regarding the long-term outcomes of MVR for IE in terms of physiologic (functional) change and arrhythmic events. With the intention of assessing hemodynamic efficacy of the On-X valve when used for mitral valve IE, we

conducted a study in which we compared functional outcomes among patients given an On-X valve and those given an SJM valve. The pathophysiology of degenerative MR differs from that of MR caused by IE. Therefore, to be able to draw reliable conclusions, we included in the study only patients who underwent MVR for IE.

2. Materials and Methods

2.1. Patients. Forty patients (24 men (60.0%) and 16 women (40.0%); mean age: 54.1 ± 13.2 years), all having undergone MVR for IE, were selected for inclusion in the study through a search of our institutions' adult cardiac surgery database. These 40 patients were the total patients aged 20 years or more who had undergone MVR for IE, and they were identified from among a total 279 consecutive patients who, between April 1990 and December 2022, had undergone surgery for IE affecting the mitral valve. The IE had been diagnosed according to the modified Duke criteria [19]. For the purpose of the study, patients were divided into two groups: an On-X group ($n = 13$) and an SJM group ($n = 27$). Patients' preoperative clinical variables and postoperative outcome variables were extracted from the adult cardiac surgery database.

Patients' preoperative characteristics are summarized per group in Table 1. Patients in the On-X group were significantly younger than those in the SJM group ($P = 0.0493$). There was no significant between-group difference in sex, medical history, or New York Heart Association functional class. Overall, *Streptococcus* was the most common causative microorganism (47.5%), followed by *Staphylococcus* (17.5%), with no significant between-group difference in the prevalence of either of these two causative agents. Treatment was based on the results of drug susceptibility testing. Thirty-eight (95.0%) of the total patients were treated for active IE and 2 (5.0%) for healed IE, with the IE judged to be active on the basis of a positive preoperative or intraoperative blood culture, continued antibiotic therapy from the time of initial diagnosis, a positive tissue culture and/or pathology report, and/or obvious vegetation during the surgery. The following were taken as indications for surgery in patients with active IE: heart failure, uncontrolled sepsis, a systemic embolic event, mobile vegetation, and severe MR due to valve destruction. Systemic embolic events and mobile vegetation as indications for surgery were significantly more common in the On-X group than in the SJM group. There was no significant between-group difference in the time from diagnosis to surgery in the cases of active IE.

The study was approved by the Institutional Review Board of Jichi Medical University (Approval no. S22-102). Informed consent was secured through an opt-out system available to patients on the institution's website.

2.2. Surgical Procedures. All surgeries were performed by experienced surgeons. On the technical side, the first step was radical debridement of infectious material, and the second step was morphologic and functional mitral valve reconstruction. The main pathologies observed at the time of surgery are shown in Table 2. The most prevalent pathologies detected during the surgery were vegetation (62.5%), a large area of leaflet destruction (42.5%), and anterior leaflet prolapse (42.5%), none of which differed significantly between the two groups. MVR was initiated when durable mitral valve repair was deemed technically infeasible, or MVR was undertaken intraoperatively if mitral valve repair failed (MR remaining above grade 2 on intraoperative echocardiography). Operative and postoperative variables, including details of the surgical procedure, are shown in Table 3. The mean operation time, mean aortic cross-clamp time, and mean cardiopulmonary bypass time did not differ between the two groups. On-X valves of size 25 mm were used in 2 cases (5.0%), of size 27/29 mm in 4 cases (10.0%), and of size 31/33 mm in 7 cases (17.5%). SJM valves of size 25 mm were used in 4 cases (10.0%), of size 27 mm in 14 cases (35.0%), of size 29 mm in 7 cases (17.5%), and of size 31 mm in 2 cases (5.0%). There was no difference in prosthesis orifice area or in patients' body surface area between the two groups. Chordae tendineae-sparing MVR was performed in all cases to prevent postoperative loss of left ventricular function. Two-dimensional transesophageal echocardiography (TEE) was performed immediately after the surgery to assess any residual MR. The MVR was combined with aortic valve replacement for IE affecting the aortic valve in 1 patient and with tricuspid valve repair in 12 patients. Antibiotic therapy was continued for 6 weeks following the surgery in all patients operated on for active IE.

2.3. Echocardiography. Two-dimensional transthoracic echocardiography (TTE) at rest was performed preoperatively, as previously described [20], and anatomic features, the extent of valve tissue destruction, and the extent of paravalvular infection were thus evaluated. TTE was also performed in the early postoperative period (up to 4 weeks after the surgery) and in the late postoperative period. The mean follow-up time was 100 months (range: 1–333 months). In addition, differences between preoperative and postoperative cardiac variables were evaluated in each group. The MR was described as mild (grade 1+ (jet area/left atrial area <10%)), moderate (grade 2+ (jet area/left atrial area 10–20%)), moderate-severe (grade 3+ (jet area/left atrial area 20–45%)), or severe (grade 4+ (jet area/left atrial area >45%)) [21]. Preoperatively, 36 (90.0%) patients had severe MR. There was no significant difference in preoperative echocardiographic variables between the two groups (Table 4). The effective orifice area (EOA) and indexed effective orifice area (EOAi) were calculated according to the continuity equation and body surface area. Investigators were blinded to patients' clinical information, and all echocardiographic data were analyzed by two experienced cardiologists.

2.4. Study Endpoints. Patients' postoperative status was monitored via outpatient clinic visits, by their general practitioners, and by telephone interview. Follow-up was continued until the patient died or until the termination of the study (December 2022). The primary study endpoint was overall mortality, i.e., in-hospital mortality, defined as death occurring within 30 days of the surgery, plus late mortality,

Table 1: Pre-operative characteristics of the total patients and per study group.

	Total ($n = 40$)	On-X group ($n = 13$)	SJM group ($n = 27$)	P value
Age (years)	54.1 ± 13.2	49.6 ± 9.8	56.3 ± 14.2	0.0493
Sex, male	24 (60.0)	8 (61.5)	16 (59.3)	>0.9999
Medical history				
Hypertension	11 (27.5)	2 (15.4)	9 (33.3)	0.2859
Dyslipidemia	4 (10.0)	1 (7.7)	3 (11.1)	>0.9999
Diabetes mellitus	2 (5.0)	2 (15.4)	0 (0.0)	0.0891
Renal dysfunction (Cr >1.5 mg/dL)	1 (2.5)	1 (7.7)	0 (0.0)	0.3250
COPD	0 (0.0)	0 (0.0)	0 (0.0)	>0.9999
Atrial fibrillation	2 (5.0)	1 (7.7)	1 (3.7)	>0.9999
Previous cardiac surgery	4 (10.0)	2 (15.4)	2 (7.4)	0.5839
NYHA functional class				
I or II	29 (72.5)	8 (61.5)	21 (77.8)	0.4507
III or IV	9 (22.5)	4 (30.8)	5 (18.5)	0.4371
Organism causing the IE				
Genus Streptococcus	19 (47.5)	9 (69.2)	10 (37.0)	0.0915
Genus Staphylococcus	7 (17.5)	3 (23.1)	4 (14.8)	0.6622
Staphylococcus aureus	7 (17.5)	3 (23.1)	4 (14.8)	0.6622
Genus Enterococcus	0 (0.0)	0 (0.0)	0 (0.0)	>0.9999
Other	0 (0.0)	0 (0.0)	0 (0.0)	>0.9999
Unidentified	13 (32.5)	1 (7.7)	12 (44.4)	0.0302
Status of the endocarditis				
Active	38 (95.0)	13 (100.0)	25 (92.6)	>0.9999
Healed	2 (5.0)	0 (0.0)	2 (7.4)	>0.9999
Indication(s) for initial surgery				
Heart failure	17 (42.5)	5 (38.5)	12 (44.4)	>0.9999
Uncontrolled sepsis	8 (20.0)	3 (23.1)	5 (18.5)	>0.9999
Systemic embolic event	17 (42.5)	11 (84.6)	6 (22.2)	0.0004
Mobile vegetation	12 (30.0)	7 (53.8)	5 (18.5)	0.0323
Severe mitral regurgitation	36 (90.0)	11 (84.6)	25 (92.6)	0.5839
Time from diagnosis to procedure (days)	11.0 ± 10.5	9.5 ± 9.8	7.1 ± 9.3	0.7827

Values are mean ± SD or n (%). COPD chronic obstructive pulmonary disease, Cr serum creatinine, IE infective endocarditis, NYHA New York heart association, SJM St. Jude Medical.

Table 2: Pathologies observed at the time of surgery among the total patients and per study group.

	Total ($n = 40$)	On-X group ($n = 13$)	SJM group ($n = 27$)	P value
Vegetation	25 (62.5)	11 (84.6)	14 (51.9)	0.0801
Perforation	4 (10.0)	1 (7.7)	3 (11.1)	>0.9999
Rupture of chordae	13 (32.5)	3 (23.1)	10 (37.0)	0.4841
Large area of leaflet destruction	17 (42.5)	8 (61.5)	9 (33.3)	0.1709
Valve prolapse				
Posterior leaflet	8 (20.0)	3 (23.1)	5 (18.5)	>0.9999
Anterior leaflet	17 (42.5)	5 (38.5)	12 (44.4)	>0.9999
Both leaflets	3 (7.5)	1 (7.7)	2 (7.4)	>0.9999
Annular abscess	4 (10.0)	0 (0.0)	4 (14.8)	0.2844

Values are n (%). SJM St. Jude Medical.

defined as death occurring beyond 30 days. Secondary endpoints were reintervention, defined as repeat mitral valve surgery for recurrent IE or recurrent MR, defined as >grade 3+ MR, and the occurrence of new-onset atrial fibrillation (AF) as an arrhythmic event.

2.5. Statistical Analysis. Data are shown as the mean ± SD values or as percentages. Between-group differences in quantitative variables were analyzed by Mann–Whitney U test, and between-group differences in qualitative variables were analyzed by the chi-square or Fisher's exact test. Univariate analysis was performed to identify factors associated with new-onset AF in each group, and variables with a P value <0.20 were entered into a Cox proportional hazards model. Hazard ratios (HRs) and their 95% confidence intervals (CIs) were calculated. All reported P values were two-tailed, and $P < 0.05$ was considered statistically significant. All analyses were performed with the use of GraphPad Prism 9 (GraphPad Software LLC, Boston, MA, USA).

Table 3: Operative and post-operative variables among the total patients and per study group.

	Total ($n = 40$)	On-X group ($n = 13$)	SJM group ($n = 27$)	P value
Operation time (minutes)	307.6 ± 86.3	288.2 ± 53.1	318.1 ± 99.3	0.4939
Aortic cross-clamp time (minutes)	115.4 ± 43.8	108.0 ± 24.4	119.2 ± 50.8	0.5412
Cardiopulmonary bypass time (minutes)	140.3 ± 54.7	133.0 ± 32.2	143.9 ± 63.4	0.5912
Size of prosthetic valves				
On-X 25 mm	2 (5.0)	2 (15.4)	N/A	
On-X 27/29 mm	4 (10.0)	4 (30.8)	N/A	
On-X 31/33 mm	7 (17.5)	7 (53.8)	N/A	
SJM 25 mm	4 (10.0)	N/A	4 (14.8)	
SJM 27 mm	14 (35.0)	N/A	14 (51.9)	
SJM 29 mm	7 (17.5)	N/A	7 (25.9)	
SJM 31 mm	2 (5.0)	N/A	2 (7.4)	
Orifice area (cm^2)	4.0 ± 0.5	4.1 ± 0.0	3.9 ± 0.6	0.0770
Body surface area (m^2)	1.6 ± 0.2	1.6 ± 0.2	1.6 ± 0.2	0.4578
Associated procedure				
CABG	0 (0.0)	0 (0.0)	0 (0.0)	>0.9999
Aortic valve replacement	1 (2.5)	1 (7.7)	0 (0.0)	0.3250
Tricuspid repair	12 (30.0)	0 (0.0)	12 (44.4)	0.0005
Post-operative hospital stay (days)	36.4 ± 27.6	45.5 ± 36.4	31.7 ± 21.0	0.2124
In-hospital mortality	0 (0.0)	0 (0.0)	0 (0.0)	>0.9999
Late mortality	6 (15.0)	0 (0.0)	6 (22.2)	0.1520
Overall mortality	6 (15.0)	0 (0.0)	6 (22.2)	0.1520
Reintervention	4 (10.0)	1 (7.7)	3 (11.1)	>0.9999
Recurrent mitral regurgitation	7 (17.5)	3 (23.1)	4 (14.8)	0.6622
Atrial fibrillation in late phase	11 (27.5)	1 (7.7)	10 (37.0)	0.0678
Biochemistry blood test in late phase				
LDH (IU/L)	315.1 ± 101.3	309.7 ± 119.8	317.6 ± 93.5	0.5442

Values are mean ± SD or n (%). CABG coronary artery bypass grafting, LDH lactate dehydrogenase, SJM St. Jude Medical.

Table 4: Pre-operative echocardiographic variables among the total patients and per study group.

	Total ($n = 40$)	On-X group ($n = 13$)	SJM group ($n = 27$)	P value
LAD (mm)	47.1 ± 10.0	43.3 ± 13.4	48.2 ± 7.5	0.0560
LVDd (mm)	53.9 ± 6.9	52.6 ± 4.7	54.3 ± 7.6	0.6439
LVDs (mm)	33.9 ± 6.0	31.2 ± 5.1	35.2 ± 6.3	0.1386
LVEF (%)	66.1 ± 8.7	69.6 ± 7.7	65.3 ± 6.4	0.0684
TR-PG (mmHg)	33.3 ± 16.8	30.1 ± 10.9	34.8 ± 19.0	0.5249
E/e'	21.7 ± 10.6	22.4 ± 11.7	19.7 ± 7.7	>0.9999
MV peak v (m/s)	1.6 ± 0.3	1.6 ± 0.3	1.7 ± 0.4	0.8857
MV max PG (mmHg)	11.5 ± 5.0	11.1 ± 7.4	11.7 ± 4.7	0.8000
MV mean PG (mmHg)	4.3 ± 2.7	4.9 ± 5.0	4.0 ± 1.8	>0.9999

Values are mean ± SD. LAD left atrial diameter, LVDd left ventricular end-diastolic diameter, LVDs left ventricular end-systolic diameter, LVEF left ventricular ejection fraction, MV mitral valve, SJM St. Jude Medical, TR-PG tricuspid regurgitation pressure gradient.

3. Results

3.1. Operative Outcomes. There was no in-hospital death in either group. Death after 30 days occurred in 6 (15.0%) of the total cases (6 cases (22.2%) in the SJM group, $P = 0.1520$). Death in the SJM group was due to intracranial hemorrhage ($n = 1$), stroke ($n = 1$), congestive heart failure ($n = 2$), sudden cardiac arrest due to ventricular arrhythmia ($n = 1$), or was sudden and of unknown cause ($n = 1$). Reintervention due to peravalvular regurgitation caused by recurrent IE was required in 4 cases (10.0%) (1 case (7.7%) in the On-X group and 3 cases (11.1%) in the SJM group), with no significant difference between the two groups ($P > 0.9999$). Seven patients (17.5%) experienced recurrent MR (3 (23.1%) in the On-X group and 4 (14.8%) in the SJM group), with no significant difference between the two groups ($P = 0.6622$). The incidence of late new-onset AF was lower in the On-X group than in the SJM group (1 case (7.7%) vs. 10 cases (37.0%), respectively; $P = 0.0678$). There was no difference in levels of lactate dehydrogenase (LDH), one of the indicators of chronic hemolysis ($P = 0.5442$).

3.2. Predictors of Late New-Onset AF. Clinical variables are shown with respect to the incidence of late new-onset AF in Table 5. On univariable analysis, age 70 and above, hypertension, EOA, and EOAi were found to be associated with late new-onset AF. After adjustment for potential

Table 5: Results of univariable and multivariable analyses for predictors of new-onset atrial fibrillation.

	Univariable analysis		P value	Multivariable analysis		P value
	HR	95% CI		HR	95% CI	
Age >70 years	15.23	0.603–385.0	0.0542			
Hypertension	2.809	0.798–11.04	0.1112			
Effective orifice area	8.181	1.915–45.82	0.0070	129.4	2.484–24195	0.0300
Indexed effective orifice area	15.81	2.376–144.7	0.0066			

CI confidence interval, HR hazard ratio.

confounders in multivariable Cox proportional hazards analysis, EOA (HR: 129.4, 95% CI: 2.484–24195; $P = 0.0300$) was identified as a significant independent predictor of late new-onset AF. The EOA and EOAi of patients in whom AF developed in the late postoperative period were significantly smaller ($P = 0.0494$ and $P = 0.0339$, respectively) than those of patients in whom AF did not develop in the late post-operative period (Table 6).

Table 6: Effective orifice area and indexed effective orifice area with respect to non-development and development of late new-onset atrial fibrillation.

	Late AF (−)	Late AF (+)	P value
EOA (cm^2)	2.5 ± 0.5	2.1 ± 0.4	0.0494
EOAi (cm^2/m^2)	1.6 ± 0.4	1.3 ± 0.3	0.0339

AF atrial fibrillation, EOA effective orifice area, EOAi indexed effective orifice area.

3.3. Echocardiography. We analyzed left atrial load and right heart load echocardiographically to clarify the relation between hemodynamic performance of the On-X valve and effectiveness of the valve in preventing new-onset AF. Postoperative echocardiographic outcomes are shown per group in Table 7. Left ventricular end-diastolic diameter (LVDd) was significantly reduced in the late postoperative period compared to that in the preoperative period in both groups, indicative of reverse remodeling. Tricuspid regurgitation pressure gradient (TR-PG) was significantly decreased in the late postoperative period compared to that in the preoperative period, but only in the On-X group. Also in this group, left atrial diameter (LAD), TR-PG, peak mitral inflow velocity (MV peak v), maximum transmitral pressure gradient (MV max PG), and mean transmitral pressure gradient (MV mean PG) were significantly decreased in the late post-operative period compared to values in the SJM group. Furthermore, the EOA and EOAi of the mitral valve were significantly larger in the On-X group. A reduction in both left atrial load and right heart load was suggested in the On-X group compared to that in the SJM group. Although the data must be interpreted by taking into account that the On-X group included fewer patients than the SJM group, improved hemodynamic performance of the valve (i.e., reduction in MV peak v, MV max PG, and MV mean PG, and increase in EOA and EOAi) were observed in the On-X group.

4. Discussion

Results of our study comparing outcomes of MVR performed with the On-X valve and outcomes of MVR performed with the SJM valve point to the benefits of the On-X valve with respect to hemodynamic performance and avoidance of new-onset AF when the procedure is carried out in patients with MR due to either active or healed IE. To the best of our knowledge, this is the first study to examine changes in echocardiographic variables from the preoperative to the early and late postoperative periods in patients treated for mitral valve IE and to address the relation between cardiac functional outcome and the occurrence of postoperative AF.

Previous studies of MVR for degenerative, rheumatic, and infective endocarditis have shown early mortality rates of 3.2–6.1% following use of the On-X valve [11, 12, 15] and 5.3–9.0% following use of the SJM valve [18, 22, 23] and 5-year survival rates of 85–90% following use of the On-X valve [10, 15, 24, 25] and 90.7% following use of the SJM valve [10]. Among our study patients, all having been treated for IE, early postoperative mortality was 0%, and survival over the entire observation period was 85.0% (On-X valve group: 100%, SJM valve group: 77.8%). IE is a rare condition that can be fatal in the absence of appropriate treatment. Because our study included only patients treated for IE, for which the prognosis is generally poor, the overall late survival rate was expected to be lower than that previously reported following MVR in cases of degenerative or rheumatic MR. However, considering that in-hospital mortality associated with IE ranges from 15% to 20%, and 1-year mortality is close to 40% [26], the survival rate documented in our study is acceptable. Only one late thromboembolic (TE) event occurred in our SJM group, resulting in death due to stroke (0.03%/patient-year). The reported incidence of late TE events following use of the ON-X valve is 1.0–1.8% per patient-year [11–13], and the reported 5-year freedom from TE following use of the ON-X valve is 96.8%, with that reported following use of the SJM valve being 95.8% [10]. One late bleeding event occurred in our SJM group, resulting in death due to cerebral hemorrhage (0.02%/patient-year). The reported incidence of late bleeding events associated with use of the On-X valve is 1.0–1.96%/patient-year [12, 13], whereas that associated with use of the SJM valve is 1.0–3.2%/patient-year [5, 27]. The incidences of late TE and late bleeding events among our study patients were lower than previously reported. The clinical outcomes of MVR in our IE-only population were satisfactory, with acceptable mortality and late TE and late bleeding event rates.

Table 7: Pre-operative and post-operative echocardiographic variables in each of the two study groups.

	Pre-operative period	Early post-operative period	Late post-operative period	*P* values		
				Pre- vs. Early	Pre- vs. Late	Early vs. Late
On-X group						
LAD (mm)	43.3 ± 13.4	39.9 ± 11.4	38.2 ± 10.8	0.5209	0.1087	0.5209
LVDd (mm)	52.6 ± 4.7	45.5 ± 5.4	43.6 ± 6.5	0.0324	0.0031	0.2828
LVDs (mm)	31.2 ± 5.1	31.1 ± 4.6	27.6 ± 4.3	0.9687	0.0599	0.1573
LVEF (%)	69.6 ± 7.7	58.7 ± 8.8	66.3 ± 7.4	0.0450	0.3648	0.1213
TR-PG (mmHg)	30.1 ± 10.9	18.3 ± 6.2	17.5 ± 5.2	0.0164	0.0008	0.6377
E/*e*′	22.4 ± 11.7	27.1 ± 10.5	30.1 ± 8.6	0.5497	0.5497	0.5497
MV peak v (m/s)	1.6 ± 0.3	1.7 ± 0.2	1.5 ± 0.3	0.7270	0.7358	0.0255
MV max PG (mmHg)	11.1 ± 7.4	13.7 ± 5.4	9.7 ± 4.0	0.5719	0.5719	0.0019
MV mean PG (mmHg)	4.9 ± 5.0	5.3 ± 2.5	3.6 ± 1.2	0.8859	0.8339	0.0485
Effective orifice area (cm^2)	—	3.1 ± 0.8	2.8 ± 0.7	—	—	0.1680
Indexed effective orifice area (cm^2/m^2)	—	2.0 ± 0.5	1.8 ± 0.5	—	—	0.1602
SJM group						
LAD (mm)	48.2 ± 7.5	45.7 ± 8.5*	50.1 ± 10.9*	0.2584	0.4061	0.0120
LVDd (mm)	54.3 ± 7.6	50.4 ± 6.7*	49.0 ± 8.0	0.0044	0.0082	0.3703
LVDs (mm)	35.2 ± 6.3	36.1 ± 6.4*	31.7 ± 7.3	0.3914	0.0619	0.0211
LVEF (%)	65.3 ± 6.4	54.8 ± 10.6	64.6 ± 9.6	0.0013	0.8020	0.0013
TR-PG (mmHg)	34.8 ± 19.0	22.4 ± 5.2	26.9 ± 9.6*	0.0371	0.2480	0.0740
E/*e*′	19.7 ± 7.7	27.4 ± 7.5	32.1 ± 10.8	0.5333	0.2052	0.5333
MV peak v (m/s)	1.7 ± 0.4	1.8 ± 0.4	1.9 ± 0.4*	0.6678	0.6678	0.6747
MV max PG (mmHg)	11.7 ± 4.7	12.7 ± 5.7	14.8 ± 5.6*	0.7543	0.6959	0.6959
MV mean PG (mmHg)	4.0 ± 1.8	5.4 ± 1.8	5.1 ± 5.8*	0.3157	0.4423	0.5156
Effective orifice area (cm^2)	—	2.7 ± 0.8	2.2 ± 0.5*	—	—	0.3652
Indexed effective orifice area (cm^2/m^2)	—	1.8 ± 0.7	1.4 ± 0.4*	—	—	0.2324

Values are mean ± SD. *$P < 0.05$ vs. On-X valve. LAD left atrial diameter, LVDd left ventricular end-diastolic diameter, LVDs left ventricular end-systolic diameter, LVEF left ventricular ejection fraction, MV mitral valve, SJM St. Jude Medical, TR-PG tricuspid regurgitation pressure gradient.

The SJM valve is a typical bileaflet-type prosthetic heart valve that has been in clinical use for many years. This valve has two flats, semicircular leaflets and a relatively high hinge position. The On-X valve has two flat semicircular leaflets that open at 90°, a relatively long support ring, and a flared inlet edge [9]. The effect of a mitrally positioned prosthetic valve on flow under pulsatile flow conditions has been studied by means of dynamic particle image velocimetry, which has shown that the SJM valve induces extensive turbulent flow, whereas the On-X valve does not divert as much flow as the SJM valve and induces clean, strong central flow [8, 9]. In addition, the On-X valve has been reported to prevent tissue interference and pannus overgrowth due to the support of the annulus and guarding of the leaflets [7, 28]. Reduced turbulence due to improved hemodynamics, pure pyrolytic carbon, reduced closing contact velocity, and smooth reverse flow patterns due to stasis-free hinges have also been reported to reduce hemolysis [7, 29]. Mechanical valves are known to induce chronic subclinical hemolysis in most patients. In general, typical mechanical bileaflet valves elevate LDH to levels approximately 120–150% of the upper limit of normal, sometimes as high as 200% of the upper limit of normal, causing anemia [16]. Furthermore, LDH elevation has been implicated in valve-related adverse events such as bleeding [30]. In this study, LDH in the late phase was 310 IU/l (124% of the upper limit of normal) in the On-X group and 318 IU/l (127% of the upper limit of normal) in the SJM group, with no significant difference. Clinical studies investigating hemolysis in patients receiving the On-X valve have shown the mean postoperative LDH level to be 271 IU/l at 3–6 months (108% of upper limit of normal), 265 IU/l at 1 year (106% of the upper limit of normal), and 253 IU/l at 5 years (101% of the upper limit of normal), indicating that use of the On-X valve results in chronic hemolysis that is milder than that reported following use of typical bileaflet mechanical valves [13, 16].

Comparison of pre- and post-MVR echocardiographic variables revealed improvement in specific variables in both the On-X group and SJM group. As shown in Table 7, early postoperative LVDd and late postoperative LVDd in our On-X group were 45.5 ± 5.4 mm and 43.6 ± 6.5 mm, respectively, both significantly improved in comparison to the preoperative value of 52.6 ± 4.7 mm. Similarly, early postoperative LVDd and late postoperative LVDd in our SJM group were 50.4 ± 6.7 mm and 49.0 ± 8.0 mm, respectively, both significantly improved in comparison to the preoperative value of 54.3 ± 7.6 mm. Left ventricular ejection fraction (LVEF) decreased significantly in both the On-X group and SJM group, from $69.6 \pm 7.7\%$ and $65.3 \pm 6.4\%$, respectively, in the preoperative period to $58.7 \pm 8.8\%$ and $54.8 \pm 10.6\%$, respectively, in the early postoperative period. However, LVEF was only somewhat improved in the late postoperative period at $66.3 \pm 7.4\%$ and $64.6 \pm 9.6\%$, respectively. TR-*PG* was 18.3 ± 6.2 mmHg and 17.5 ± 5.2 mmHg in the early and late postoperative periods in the On-X group, both values significantly improved in comparison to the preoperative value of 30.1 ± 10.9 mmHg. In our SJM group, TR-*PG* was 22.4 ± 5.2 mmHg in the early postoperative period, a significant decrease from the preoperative value of 34.8 ± 19.0 mmHg. However, in the late postoperative period, TR-*PG* in this group was 26.9 ± 9.6 mmHg, again elevated. In the early postoperative period, LAD, LVDd, and left ventricular end-systolic diameter (LVDs) in our On-X group were 39.9 ± 11.4 mm, 45.5 ± 5.4 mm, and 31.1 ± 4.6 mm, respectively, values significantly lower than the respective 45.7 ± 8.5 mm, 50.4 ± 6.7 mm, and 36.1 ± 6.4 mm in our SJM group. Furthermore, in the late postoperative period, LAD in our On-X group was 38.2 ± 10.8 mm, significantly lower than the 50.1 ± 10.9 mm in our SJM group. A previous study comparing the On-X valve to the SJM valve as used for MVR showed the maximum and mean pressure gradients across the On-X valve to be smaller, though not significantly smaller, than those across the SJM valve [18]. MV peak v, MV max PG, and MV mean PG in our On-X group were 1.5 ± 0.3 m/s, 9.7 ± 4.0 mmHg, and 3.6 ± 1.2 mmHg, respectively, all significantly lower than the respective 1.9 ± 0.4 m/s, 14.8 ± 5.6 mmHg, and 5.1 ± 5.8 mmHg in our SJM group. The EOA is utilized to characterize hemodynamic performance of a heart valve. EOA and EOAi were $2.8 \pm 0.7\ cm^2$ and $1.8 \pm 0.5\ cm^2/m^2$, respectively, in our On-X group and $2.2 \pm 0.5\ cm^2$ and $1.4 \pm 0.4\ cm^2/m^2$ in our SJM group, both significantly higher in our On-X group than in our SJM group. This trend was comparable to that of a previous study [18, 31] that documented respective EOA and EOAi values of 2.0–2.4 cm^2 and 1.1–1.3 cm^2/m^2 in the On-X group and 1.9–2.2 cm^2 and 1.0–1.28 cm^2/m^2 in the SJM group. The above-mentioned decrease in transvalvular pressure gradient, significant increase in EOA and EOAi, and effective reduction in LAD in the On-X valve confirm that, when used in the mitral position, the On-X valve has similar or better hemodynamic performance than the SJM valve. The hemodynamic effects of MVR on cardiac events have been investigated, and high mitral pressure gradients can increase left atrial and pulmonary arterial pressures, leading to pulmonary arterial hypertension followed by right-sided heart failure [18]. It has also been noted that persistently high left atrial pressure may increase the incidence of AF [18]. The present study also showed that EOA and EOAi are factors influencing the occurrence of late new-onset AF, with EOA in particular being an independent predictor of late new-onset AF. Some studies have indicated that the EOAi of an artificial mitral valve should be >1.2–1.3 cm^2/m^2 to avoid a high transvalvular pressure gradient [32, 33]. EOA, EOAi, and pressure gradients achieved with the use of the On-X valve in the mitral position may reduce the incidence of new-onset AF in the late phase.

The limitations of the study include, first, its design as a retrospective, nonrandomized, single-center observational study. Second, the sample size was small, and the mean follow-up period was short. With a larger sample size and a longer follow-up period, results might differ. Third, surgical techniques and approaches, which have improved over the past 30 years, may have influenced the study results. Further research is needed on the relative benefits (i.e., long-term clinical outcomes in mortality, thrombosis, hemorrhage, reverse remodeling of the ventricle, and association between hemodynamic load and AF) of the On-X valve vs. the SJM valve.

5. Conclusion

MVR performed with the On-X valve is an attractive surgical option for patients with mitral valve IE, with its associated mortality and morbidity rates being comparable to those associated with the use of the SJM valve plus its superior hemodynamic performance. EOA appears to be of independent predictive value for the occurrence of late-new-onset AF in patients who have undergone MVR for IE. The EOA achieved with the use of the On-X valve in the mitral position may reduce the incidence of new-onset AF in the late phase.

Data Availability

The patient data used to support the findings of this study are restricted by the Institutional Review Board of Jichi Medical University in order to protect patient privacy. Data are available from Manabu Shiraishi, manabu@omiya.jichi.ac.jp for researchers who meet the criteria for access to confidential data.

Ethical Approval

Approval no. S22–102.

Consent

Patients waived informed consent by the opt-out method.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

MS was responsible for study design, analysis, and interpretation. MS, ST, KT, and HA were reponsible for data acquisition. MS was drafting the manuscript: . MS, NK, and AY critically revised the manuscript. MS, ST, KT, HA, NK, and AY approved the submitted and final version.

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