Original Article

Percutaneous coronary intervention followed by minimally invasive valve surgery compared with median sternotomy coronary artery bypass graft and valve surgery in patients with prior cardiac surgery

Orlando Santana[1], Steve Xydas[2], Roy F. Williams[2], Angelo LaPietra[2], Maurice Mawad[2], Jason C. Wigley[3], Nirat Beohar[1], Christos G. Mihos[4]

[1]The Columbia University Division of Cardiology, [2]The Division of Cardiac Surgery, [3]The Department of Anesthesia, Mount Sinai Medical Center, Miami Beach, Florida, USA; [4]Cardiac Ultrasound Laboratory, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Contributions: (I) Conception and design: O Santana, RF Williams, CG Mihos; (II) Administrative support: None; (III) Provision of study materials or patients: None; (IV) Collection and assembly of data: O Santana, CG Mihos; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Orlando Santana, MD. Director, Echocardiography Laboratory, Columbia University Division of Cardiology, Mount Sinai Heart Institute, 4300 Alton Road, Miami Beach, Florida 33140, USA. Email: osantana@msmc.com.

Background: In patients with prior cardiac surgery requiring re-operative coronary and valve surgery, a hybrid approach of percutaneous coronary intervention followed by minimally invasive valve surgery (PCI + MIVS) may be an alternative to the standard median sternotomy coronary artery bypass and valve surgery (CABG + valve).

Methods: The outcomes of patients with prior cardiac surgery, presenting with coronary artery and valvular disease, who underwent PCI + MIVS (N=39) were retrospectively compared with those who underwent CABG + valve (N=28) via a repeat median sternotomy, between February 2009 and April 2014.

Results: The mean age for the PCI + MIVS versus CABG + valve group was 75±9 and 72±11 years (P=0.54), respectively. The baseline characteristics were similar between groups, with the exception of a greater prevalence of 1-vessel coronary artery disease and clopidogrel or dual antiplatelet therapy at the time of surgery in the PCI + MIVS group, and more 3-vessel coronary artery disease in those undergoing CABG + valve surgery. The PCI + MIVS approach was associated with a decreased aortic cross-clamp (94 *vs*. 131 minutes, P=0.001) and cardiopulmonary bypass (128 *vs*. 190 minutes, P<0.001) times, fewer intraoperative packed red blood transfusions (1.3 *vs*. 3.8 units, P=0.001), shorter intensive care unit length of stay (41 *vs*. 71 hours, P<0.001), and decreased incidence of prolonged mechanical ventilation (12.8% *vs*. 35.7%, P=0.03), re-intubation (2.6% *vs*. 17.9%, P=0.04), when compared with CABG + valve. The thirty-day and two-year mortality were similar, being 7.7% *vs*. 7.1% (P=0.66), and 12.8% *vs*. 10.7% (P=0.55), in the PCI + MIVS *vs*. CABG + valve group, respectively.

Conclusions: Hybrid PCI + MIVS in patients with prior cardiac surgery is associated with shorter operative times and intensive care unit length of stay, less need for intraoperative blood cell transfusions, decreased use of mechanical ventilation, and similar short-term and follow-up survival, when compared with CABG + valve surgery via median sternotomy. Randomized trials and multicenter registries are needed to further evaluate this approach.

Keywords: Coronary artery disease; re-operative; percutaneous coronary intervention; minimally invasive valve surgery

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Introduction

The incidence of re-operative valve surgery is increasing owing to improved surgical techniques, a greater survival rate after cardiac surgery, and an increased aging population (1). In patients with a prior sternotomy, valvular surgery via repeat median sternotomy (ST) carries significant risks, including increased bleeding, possible injury to cardiac structures or patent grafts, and a higher operative mortality (2-5). By utilizing a minimally invasive approach in patients requiring re-operative valve surgery, one may avoid a repeat ST, the need for dissection of pericardial adhesions, and reduce surgical trauma. Indeed, minimally invasive valve surgery (MIVS) in patients undergoing re-operative surgery is associated with less bleeding, reduced blood transfusions, absence of deep sternal wound infections, shorter hospital length of stay, and improved post-operative outcomes (6-8).

In patients with a history of prior cardiac surgery requiring re-operative coronary artery revascularization and valve surgery (CABG + valve), performing percutaneous coronary intervention (PCI) for revascularization permits the use of minimally invasive surgical techniques (a "hybrid" approach), and avoids performing a combined CABG + valve surgery via a repeat ST (9-16). Hybrid PCI + MIVS has been demonstrated to be associated with less bleeding, lower resource utilization, less composite complications, and at least comparable clinical outcomes, when compared with primary CABG + valve surgery (12,15,16). We hypothesized that in patients requiring re-operative CABG + valve surgery, PCI + MIVS may offer an alternative to the standard CABG + valve surgery via ST. Herein, we compared the outcomes of patients with a history of cardiac surgery performed via ST who underwent re-operative PCI + MIVS versus CABG + valve surgery via repeat ST.

Methods

This study was approved by the Institutional Review Board at Mount Sinai Medical Center, Miami Beach, Florida. A retrospective review of our Institutional Society of Thoracic Surgeons (STS) database was performed to identify patients with a history of cardiac surgery who subsequently presented with coronary artery and valvular disease requiring repeat surgical intervention between February 2009 and April 2014. The outcomes of those who underwent PCI + MIVS were compared with those who underwent CABG + valve surgery via ST.

The definitions and variables selected were based on the STS database definitions. The variables analyzed were operative mortality, as well as, postoperative complications. Operative mortality was defined as death within 30 days of surgery, or at any time after the operation if the patient was not discharged from the hospital alive. Operative times, as well as intensive care unit and total hospital lengths of stay, were also assessed. Patients undergoing emergency surgery, those with endocarditis, and those undergoing a concomitant procedure of the aorta were excluded. All surviving patients were evaluated in the outpatient setting 30 days after surgery by the Heart Valve Team. Follow-up data concerning survival and major adverse cardiac and cerebrovascular events (MACCE) were assessed by searching local electronic health records, cardiology office follow-up visits, and a telephone follow-up survey every six months using a questionnaire approved by the Institutional Review Board. Vital status for all patients was also assessed with the Social Security Death Index.

Patient selection and technique for PCI + MIVS

In all patients, the coronary and valvular lesions were documented by diagnostic catheterization and echocardiography. The decision to proceed with a strategy of PCI + MIVS was made by the Heart Valve Team, with consideration of the coronary anatomy and feasibility of PCI, co-morbidities and surgical risk factors, and patient preference. A loading dose of 600 mg of clopidogrel and 325 mg of aspirin was administered at the time of stent placement, followed by clopidogrel 75 mg daily and aspirin 81 to 325 mg daily. Patients continued their anti-platelet therapy up to the day of MIVS and this was resumed on day one or two post-operatively.

Our MIVS approach has been described previously in detail, with a brief summary provided herein (17). For aortic valve procedures, a 5–6 cm right transverse skin incision was made 1 cm lateral to the sternum over the 2nd to 3rd intercostal space. The 2nd or 3rd costochondral cartilage was transected for the surgery, and then re-attached at the conclusion of the procedure. For combined aortic and mitral valve procedures, a 6–7 cm incision is performed over the 4th intercostal space starting at the mid-clavicular line. In patient undergoing mitral valve surgery, a 5–6 cm skin incision was made in the 4–5th intercostal space lateral to the anterior axillary line. The mitral valve was accessed through Waterston's groove, with the typical left atriotomy. Finally, in combined mitral and tricuspid valve surgery, a 6 cm incision was made in the right 4th to 5th intercostal

Table 1 Patient baseline characteristics

Variables	PCI + MIVS, N=39	CABG + valve, N=28	P value
Age (years, mean ± SD)	75±9	72±11	0.54
Male gender	33 (84.6%)	25 (89.3%)	0.43
Left ventricular ejection fraction (median, IQR)	50% [40–58]	53% [45–60]	0.26
Body mass index (kg/m², median, IQR)	26 [25–29]	28 [25–30]	0.49
Hypertension	38 (97.4%)	28 (100%)	0.58
Diabetes mellitus	15 (38.5%)	10 (35.7%)	0.51
Cerebrovascular disease	10 (25.6%)	7 (25.0%)	0.59
Peripheral vascular disease	6 (15.4%)	5 (17.9%)	0.52
Preoperative creatinine (mg/dL, median, IQR)	1.1 (0.9–1.3)	1.2 (0.9–1.4)	0.62
Prior myocardial infarction	19 (48.7%)	10 (35.7%)	0.21
Prior coronary artery bypass graft surgery	25 (64.1%)	14 (50.0%)	0.44
Prior valve surgery	8 (20.5%)	7 (25.0%)	0.18
Prior coronary artery bypass graft and valve surgery	6 (15.4%)	7 (25.0%)	0.25
Pre-operative aspirin use	28 (71.8%)	9 (32.1%)	0.1
Pre-operative clopidogrel use	30 (76.9%)	4 (14.3%)	<0.001
Pre-operative dual antiplatelet therapy use	26 (66.7%)	4 (14.3%)	<0.001

CABG + valve, coronary artery bypass grafting and valve surgery; IQR, interquartile range; PCI + MIVS, percutaneous coronary intervention and minimally invasive valve surgery; SD, standard deviation.

space lateral to the anterior axillary line.

Statistical methods

All continuous variables were expressed as the median and interquartile range (IQR, or 25%–75%) or mean ± 1 standard deviation (SD). Continuous variables with normal distribution were analyzed using Student's *t*-test. The Mann-Whitney U-test was utilized to compare those variables with nonparametric distributions. All dichotomous variables were compared using chi-square analysis. A two-tailed P value of <0.05 was considered statistically significant. The statistical analyses were conducted using Statistical Package for Social Sciences, version 21 (SPSS Inc., Chicago, IL, USA).

Results

There were 67 patients identified with a history of prior cardiac surgery that required coronary artery revascularization and valve surgery, of which 39 underwent PCI + MIVS and 28 underwent CABG + valve surgery via repeat ST. There were 33 (84.6%) men in the PCI + MIVS group and 25 (89.3%) in the CABG + valve group (P=0.43), with a mean age of 75±9 and 72±11 years (P=0.54), respectively. There were no significant differences in the types of previous cardiac surgery between the two groups. In the PCI + MIVS group, this consisted of CABG in 25 (64.1%) patients, valve surgery in 8 (20.5%), and CABG + valve surgery in 6 (15.4%). In the CABG + valve group, there were 14 (50%) with prior CABG, 7 (25%) with prior valve surgery, and 7 (25%) with prior CABG + valve surgery. The baseline characteristics were similar between both groups, with the exception of a higher pre-operative use of clopidogrel and dual antiplatelet therapy in the PCI + MIVS group compared with the CABG + valve group, being 30 (76.9%) *vs.* 4 (14.3%), (P<0.001), and 26 (66.7%) *vs.* 4 (14.3%), (P<0.001), respectively (*Table 1*).

In the PCI + MIVS group, 20 (51.2%) of the patients had their PCI at another hospital, and were referred to our Medical Center for their valve surgery. There were 35 (89.7%) patients who had 1-vessel, and 4 (10.3%) had 2-vessel PCI, with a median of 1 stent (IQR, 1–2) placed (*Table 2*). The median time from PCI to MIVS was

Table 2 Comparison of the number of disease vessels between the PCI + MIVS and CABG + valve groups

Coronary artery anatomy	PCI + MIVS, N=39	CABG + valve ,N=28	P value
1-vessel coronary artery disease	35 (89.7%)	6 (21.4%)	<0.001
2-vessel coronary artery disease	4 (10.3%)	4 (14.3%)	0.45
3-vessel coronary artery disease	0	18 (64.3%)	<0.001
Left main coronary artery disease	4 (10.3%)	7 (25.0%)	0.1
Proximal left anterior descending coronary artery	6 (15.4%)	3 (10.7%)	0.43

CABG + valve, coronary artery bypass grafting and valve surgery; PCI + MIVS, percutaneous coronary intervention and minimally invasive valve surgery.

Table 3 Surgical characteristics

Variable	PCI + MIVS, N=39	CABG + valve, N=28	P value
Aortic valve replacement	16 (41.0%)	16 (57.0%)	0.36
Mitral valve replacement	7 (17.9%)	3 (10.7)	0.68
Mitral valve repair	7 (17.9%)	2 (7.1%)	0.39
Aortic valve and mitral valve replacement	5 (12.8%)	2 (7.1%)	0.83
Aortic valve replacement and mitral valve repair	2 (5.1%)	5 (17.9%)	0.18
Mitral valve replacement and tricuspid valve repair	2 (5.1%)	0	0.64
Cardiopulmonary bypass time (min, median, IQR)	128 [100–158]	190 [146–219]	<0.001
Aortic cross clamp time (min, median, IQR)	94 [77–122]	131 [105–152]	0.001
Intra-operative packed red blood cells transfusion (units, mean ± SD)	1.3±1.5	3.8±3.1	<0.001

CABG + valve, coronary artery bypass grafting and valve surgery; IQR, interquartile range; PCI + MIVS, percutaneous coronary intervention and minimally invasive valve surgery; SD, standard deviation.

43 (IQR, 19–71) days. In this group, single valve surgery was performed in 30 (76.9%) patients, consisting of 16 (41%) aortic valve replacements, 7 (17.9%) mitral valve replacements, 7 (17.9%) mitral valve repairs, and 9 (23.1%) double valve operations. Adequate exposure of the surgical field was obtained in all the minimally invasive operations, with no patients requiring conversion to a full sternotomy. In patients undergoing CABG + valve surgery, the prevalence of 1-, 2-, and 3-vessel coronary artery disease was 6 (21.4%), 4 (14.3%),and 18 (64.3%). Single valve surgery was performed in 21 (83.3%) patients, consisting of 16 (57%) aortic valve replacements, 3 (10.7%) mitral valve replacements, 2 (7.1%) mitral valve repairs, and 7 (25%) double valve operations. There was no significant difference between the two groups in regards to the type of valve surgery performed (*Table 3*).

The median aortic cross-clamp and cardiopulmonary bypass times were 94 (IQR, 77–122) and 128 minutes (IQR, 100–158) for the PCI + MIVS group, versus 131 (IQR, 105–152) and 190 minutes (IQR, 146–219) for the CABG + valve group (P=0.001 and <0.001, respectively). The mean number of packed red blood cells units transfused intra-operatively were significantly lower in the PCI + MIVS group, being 1.3±1.5 *vs.* 3.8±3.1 units (P<0.001) (*Table 3*). The median intensive care unit length of stay was 41 hours (IQR, 23–50) *vs.* 71 (IQR, 47–113) for the PCI + MIVS and CABG + valve group (P<0.001), with a median total hospital length of stay of 6 days (IQR, 5–10) and 9 (IQR, 6–17), respectively (P=0.07). Additionally, patients who underwent PCI + MIVS had a lower prevalence of prolonged mechanical ventilation and re-intubation, which occurred in 5 (12.8%) and 1 (2.6%) patients, respectively, as compared with the CABG + valve group, in which there were 10 (35.7%) and 5 (17.9%) occurrences (P=0.03 and P=0.04, respectively). The operative mortality was 3 (7.7%) and 2 (7.1%) in the PCI + MIVS and CABG

Table 4 Post-operative characteristics

Variables	PCI + MIVS, N=39	CABG + valve, N=28	P value
Total intensive care unit length of stay (hours, median, IQR)	41 [23–50]	71 [47–113]	<0.001
Total hospital length of stay (days, median, IQR)	6 [5–10]	9 [6–17]	0.07
Atrial fibrillation	11 (28.2%)	12 (42.9%)	0.16
Cerebrovascular accident	0	0	–
Re-operation for bleeding	2 (5.1%)	4 (14.3%)	0.19
Acute kidney injury	1 (2.6%)	2 (7.1%)	0.38
Q-wave myocardial infarction	0	0	–
Prolonged mechanical ventilation (>24 hours)	5 (12.8%)	10 (35.7%)	0.03
Re-intubation	1 (2.6%)	5 (17.9%)	0.04
Operative mortality	3 (7.7%)	2 (7.1%)	0.66
All-cause of mortality at a median of 24 months follow-up	5 (12.8%)	3 (10.7%)	0.55

CABG + valve, coronary artery bypass grafting and valve surgery; IQR, interquartile range; PCI + MIVS, percutaneous coronary intervention and minimally invasive valve surgery.

+ valve group, respectively (P=0.66), and at a median follow-up of 24 months (IQR, 12–37), the all-cause mortality was 5 (12.8%) for the PCI + MIVS group, and 3 (10.7%) in the CABG + valve group (P=0.55) (*Table 4*).

Discussion

In patients with prior sternotomy requiring cardiac valve surgery, sternal re-entry carries significant risk of peri-operative complications, with operative mortality rates as high as 17% for isolated cardiac valve surgery (18,19). Injury to vascular structures or coronary artery grafts is a major concern, and mediastinal scarring and adhesions tend to make the intervention technically difficult. In patients requiring CABG + valve surgery, re-operation is even more challenging. In the present study, a strategy of hybrid PCI + MIVS when compared with CABG + valve surgery was associated with: (I) less need for intra-operative blood transfusions, despite a much higher prevalence of pre-operative clopidogrel or dual antiplatelet therapy usage; (II) a reduction in prolonged mechanical ventilation and re-intubation; (III) a faster post-operative recovery, as evidenced by a shorter intensive care unit length of stay; and, (IV) comparable operative mortality and early follow-up survival rates.

In general, MIVS is associated with longer operative times when compared with ST (20,21). However, by performing PCI to treat the coronary artery disease, one obviates the necessity of performing concomitant CABG at the time of surgery, significantly reducing the complexity of the surgery and shortening the operative times, which was noted in our study when compared with repeat ST. The less traumatic nature of MIVS and reduced operative times likely conferred lower transfusion requirements, despite more patients being on dual anti-platelet therapy. Although, our study was not powered to detect a statistically significant difference, shorter operative times and less blood product use during cardiac surgery are associated with fewer infections, and a lower morbidity and mortality (22,23).

After a median sternotomy, there are decreases in forced vital capacity, expiratory volume in the first second of forced expiration, peak expiratory flow rate, and maximum voluntary ventilation (24). The respiratory function is further impaired when there is harvesting of the internal mammary artery which causes a reduced blood supply to the intercostal muscles, which may decrease the forces of respiration with a corresponding decrease in pulmonary mechanics (25). Both of these issues, associated with ST and internal mammary harvesting, are typically avoided by the use of a PCI + MIVS approach. The present study confirmed this, demonstrating a significantly lower incidence of prolonged ventilation and re-intubation, leading to shorter intensive care unit length of stay with the PCI + MIVS approach, when compared with ST. These benefits of reduced ventilation times, and shorter intensive care unit length of stay, have been consistently demonstrated in

patients with a previous ST who underwent a re-operative valve surgery via a minimally invasive approach (6-8).

A potential limitation of MIVS in patients undergoing re-operative valve surgery is the ability to obtain adequate exposure of the surgical field. In circumstances when adequate exposure cannot be obtained, the surgery may need to be converted to ST. The conversion rate of a MIVS to ST is approximately 2.6% to 4.0% (26). Obtaining appropriate exposure was not found to be a problem in our cohort, and none of the patients who underwent MIVS needed to be converted to ST.

The present study is subject to the limitations inherent to a single-center retrospective study. Firstly, its retrospective nature, and the selection of patients for PCI + MIVS based on the coronary anatomy confers a significant treatment selection bias. Secondly, the cohort consisted of a heterogeneous group of patients undergoing single vessel or multi-vessel PCI, and receiving different types of re-operative valve surgery. Patients undergoing PCI + MIVS had a greater prevalence of 1-vessel disease, while the CABG + valve group had more 3-vessel disease, introducing an uncontrollable confounder given the preference of CABG in this group of patients (27). Nevertheless, there were similar rates of left main and proximal left anterior coronary artery disease between the groups, suggesting a similar distribution of higher risk coronary lesions. Thirdly, follow-up outcomes were limited to all-cause mortality, with no data available on the development of target vessel revascularization or myocardial infarction, which are important determinants of long-term PCI success. Finally, the study sample size was small, which limited the statistical power and may underestimate differences in demographics and clinical variables and outcomes.

In conclusion, the present study suggests that in patients with prior cardiac surgery requiring re-operation for concomitant coronary artery and valvular disease, a hybrid approach of PCI + MIVS for single or double valve surgery is associated with shorter operative times, a lower blood transfusion requirement, and a reduction in prolonged mechanical ventilation with similar short-term and follow-up survival when compared with CABG + valve via ST. However, our sample size is small, and heterogeneous, limiting the conclusions that can be drawn. Our results are best interpreted as providing evidence for the safety and feasibility of MIVS via a right thoracotomy as an acceptable alternative to conventional median repeat sternotomy, for patients with previous cardiac surgery that require a re-operation for coronary artery and valvular disease.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: This study was approved by the Institutional Review Board at Mount Sinai Medical Center, Miami Beach, Florida.

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