Mini-Sternotomy versus Conventional Total Sternotomy for Aortic Valve Replacement

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ABSTRACT

This study compares postoperative outcomes in patients undergoing Aortic Valve Replacement (AVR) surgeries through the mini- and conventional sternotomy techniques.

Methods: This is a retrospective comparative analysis of 90 consecutive patients who underwent mini-sternotomy (mAVR) and conventional total-sternotomy (cAVR) and was divided into two separate equal groups to analyze their cardiopulmonary bypass (CPB) and aortic clamping time, surgical bleeding volume, mechanical ventilation time, atrial fibrillation incidence, ICU stay, mortality within one-month, post-operative bleeding within 24hr and bleeding required transfusion. In this study, we excluded patients who underwent a combined procedure, reoperation surgery, and unavailable medical records. ANOVA test has been utilized to evaluate the potentially significant differences between the two surgical techniques.

Results: There was a difference between the mAVR and cAVR patients regarding CPB duration, in the mAVR (Range = 82- 114 minutes, Mean= 98 minutes, STD deviation= 6.32 minutes), while cAVR (Range= 61-79 minutes, Mean = 69.80 minutes, STD deviation= 4.53 minutes). The aortic cross- clamping time in the mini sternotomy (Range = 56- 80 minutes, Mean= 67.89 minutes, STD deviation= 6.96 minutes), while conventional sternotomy (Range= 36-56 minutes, Mean = 46.64 minutes, STD deviation= 5.72 minutes).The length of intensive care unit (ICU) stay in hours was shorter for the mAVR patients (Range= 8-64, Mean = 35.87, STD deviation= 13.81 hours), against that for the cAVR patients (Range= 23-127, Mean = 55.09, STD deviation= 20.08 hours). The mechanical ventilation (MV) duration for the mAVR (Range= 6-16 hours, Mean = 11.11 hours, STD deviation= 2.76 hours), against that for the cAVR patients (Range= 6-20 hours, Mean = 12.82 hours, STD deviation= 3.62 hours). The postoperative bleeding within 24 hours for the mAVR patients (Range= 135-365 ml, Mean = 248.67 ml, STD deviation= 36.34 ml), against that for the cAVR patients (Range= 235-705 ml, Mean = 473.44 ml, STD deviation= 98.92 ml).

In the first 24 hours, only 10 patients of the mAVR group needed a total of 13 units of packed RBC, whereas 16 patients of cAVR required 27 units. Mediastinal re-exploration for bleeding issues was required in one mAVR and two cAVR patients. The atrial fibrillation for the mAVR patients and cAVR patients were 6 out of 45 patients in each surgery technique. The mortality cases within the month were qual between each group, one case in the mAVR patients and one in the cAVR patients.

In terms of the significance of the differences between the mAVR patients and cAVR patients, concerning Cardiopulmonary bypass, aortic clamping time, mechanical ventilation time, ICU time, postoperative bleeding are significantly different with p-value (0.000, 0.000, 0.014, 0.000, 0.000) respectively, but there were insignificant differences between the mAVR patients and cAVR patients in atrial fibrillation incidence, bleeding required transfusion, a number of packed RBC, mortality case with p-value (1.000, 0.167, 0.058,1.000) respectively.

Conclusions: Mini-sternotomy is relatively less invasive, has lesser postoperative comorbidities, and reduced ICU stay as compared with conventional sternotomy.

Keywords: Aortic valve replacement, minimally invasive surgery, conventional sternotomy, mini-sternotomy.

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INTRODUCTION

AVR is of the most commonly performed procedures by cardiovascular surgeons worldwide, especially given the rising burden of the elderly population (1, 2). Conventional median sternotomy has been the procedure of choice for AVR surgeries for decades (3-5). However, recently, its proponents have started claiming that there are more benefits in adopting the mini-sternotomy approach instead of the conventional approach in AVR surgeries (6, 7). The idea of using new approaches must always be that they are safe, effective, and have better or, at least, the same final operative results for them to be justified (8).

For AVR surgery procedures, partial upper sternotomy has been proven to provide the same operative results as conventional sternotomy (9-11). By adopting minimal access strategies, the surgeon must ensure that the basic principles of valvular surgery remain uncompromised (12). If minimal access surgery provides comparatively better operative safety and quality, this approach may be accorded priority (13, 14).

The first description of the minimally invasive AVR surgery was in 1993 (15). Subsequently, it got popularized in 1996 and 1997 (16) as an alternative to cAVR in approaching isolated AVR or ascending aorta disease. Many approaches have been known, but mAVR (partial upper Hemi-sternotomy extended in J shape into the right 4^{th} intercostal space) is the most frequently used (17).

In 2008, the American Heart Association defined minimally invasive surgery as "a small chest wall incision that does not include the conventional full sternotomy” (6).

Because of mAVR’s favorable results, it became the standard procedure in many centers with a high volume of AVRs (18). These advantages include a smaller cosmetic incision along with a minimization in postoperative bleeding, transfusion requirement, rate of atrial fibrillation, length of mechanical ventilation, length of ICU stays, and postoperative pain with no difference in mortality (7, 19, 20).

METHODS

This is a retrospective comparative analysis of 90 consecutive patients who underwent isolated AVR from January 2014 to December 2018 at the Queen Alia Heart Institute. The relevant data were collected from patients' medical and surgical records. The medical records were reviewed for age, gender, body mass index (BMI), and New York Heart Association’s (NYHA) functional classification at time of surgery, left ventricular ejection fraction, primary pathology of the aortic valve, atrial fibrillation, and comorbidities like diabetes, dyslipidemia, renal insufficiency, previous cerebrovascular accidents, and peripheral vascular disease.

From our surgical notes, we reviewed the type of surgery, type of valve prosthesis used, time of CPB and aortic clamping, the volume of surgical bleeding, the time of mechanical ventilation, the need for blood transfusion, the incidence of atrial fibrillation, the length of ICU stays and early mortality.

The patients were divided into the following two groups: group (A) patients had undergone mAVR, and group (B) patients had undergone cAVR. The collected data of the two groups were analyzed and compared in keeping with the objective of this study. We excluded patients who underwent a combined aortic valve surgery, redo cardiac surgery, and inaccessible medical records.

Our institution's ethics committee for research had approved this study.

Operative techniques

Surgical conduct was performed by administering general endotracheal anesthesia in the supine position with the external defibrillator pads fixed on the chest wall and the trans-esophageal echocardiography in place.

In mAVR patients, via a 5–8 cm skin incision, the upper sternotomy was opened by a slandered saw extending from the suprasternal notch to the right fourth intercostal space (figure no 1) with due caution exercised to avoid injury to the right internal mammary artery.

Figure No 1: Shows small skin incision and upper sternotomy after opened by a slandered saw in mini-sternotomy Aortic Valve Replacement (mAVR) surgery

After pericardiotomy and pericardial traction sutures, the ascending aorta and right atrium were exposed. Thereafter, the patient was fully heparinized.

Aortic cannulation and dual-stage venous cannula were placed. A left ventricular vent was inserted in the upper right pulmonary vein (see figure no 2). The extracorporeal circulation was initiated, and the aorta was cross-clamped. After that, cold antegrade cardioplegia solution was instilled via the aortic root or coronary Ostia in the case of significant aortic insufficiency. The standard technique of AVR was then performed. A ventricular pacing wire was placed on the anterior surface of the right ventricle. Thereafter, de-airing, de-clamping, and weaning from the bypass were performed as usual. Finally, the pericardial drain was introduced and sternum closure was performed. Conventional AVR was performed in the same fashion except that in its case full sternotomy was used.

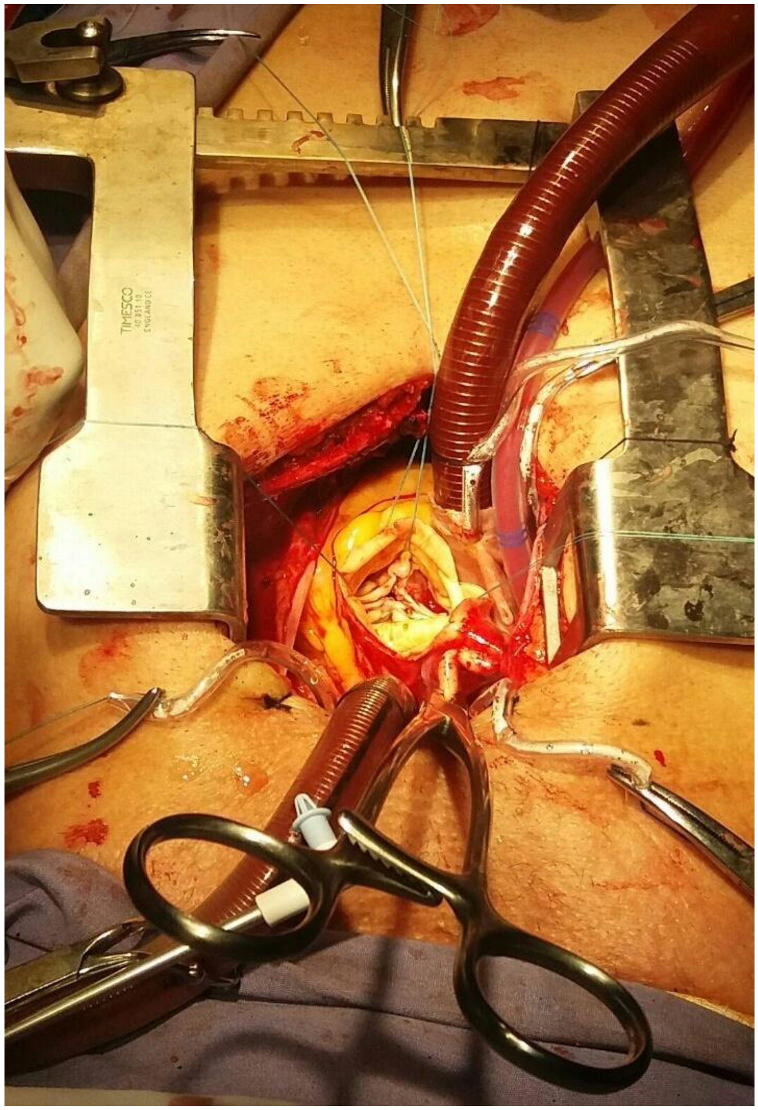

Figure No 2: Limited surgical field in mini-sternotomy aortic valve replacement surgery. The surgical window is occupied by two venous cannulae of superior and inferior vena cava with snares and right-sided superior pulmonary vent cannula. In the center of the field, Aortotomy showing a diseased and thickened aortic valve leaflet, and three stay sutures raising the commissures of valve leaflets.

Statistical strategy

The study aimed to examine the differences between patients who underwent AVR surgeries through the mini sternotomy and conventional sternotomy techniques. By doing so, we attempt to address the following questions. 1. Is there a difference in cardiopulmonary bypass (CPB) between patients who underwent Conventional sternotomy versus Mini-sternotomy? 2. Is there a difference in aortic clamping time between patients who underwent Conventional sternotomy versus Mini-sternotomy? 3. Is there a difference in mechanical ventilation time between patients who underwent Conventional sternotomy versus Mini-sternotomy? 4. Is there a difference in atrial fibrillation incidence between patients who underwent Conventional sternotomy versus Mini-sternotomy? 5. Is there a difference in ICU stay between patients who underwent Conventional sternotomy versus Mini-sternotomy? 6. Is there a difference in Postoperative bleeding within 24hr between patients who underwent Conventional sternotomy versus Mini-sternotomy? 7. Is there a difference in the number of packed RBC units between patients who underwent Conventional sternotomy versus Mini-sternotomy? 8. Is there a difference in Mortality within one month between patients who underwent Conventional sternotomy versus Mini-sternotomy?

To answer these questions, The Factorial Analysis of Variance (ANOVA) has been utilized to mathematically evaluate the significance of mean differences of an outcome and a factor. In essence, ANOVA identifies the potential differences between mini sternotomy and conventional sternotomy techniques.

RESULTS

Between January 2014 and December 2018, a total of 90 consecutive patients underwent isolated AVR in our institution. Half of them (n = 45) had undergone mAVR, and the other half had undergone cAVR.
The preoperative patient's demographics are summarized in Table I.
The mean age for mAVR patients was 67 ± 10 years as compared to 65 ± 12 years for cAVR patients. The two groups were comparable in terms of age, gender, and BMI. Aortic stenosis was the most common indication for surgery in both groups (n = 82 cases), (mAVR = 42 cases, cAVR = 40 cases). Aortic regurgitation was found in 8 cases (mAVR = 3, cAVR = 5). Baseline left ventricular ejection fraction was almost similar for both the groups (mAVR = 55 ± 9%, cAVR = 56 ± 9%). NYHA class III/IV was present in 37% of the mAVR patients and 35.8% of the cAVR patients.

The descriptive statistics results, as it is illustrated in Table II, show that the mAVR patients regarding CPB duration in minutes (Range = 82- 114, Mean= 98, STD deviation= 6.32 minutes). The aortic cross-clamping time in minutes (Range = 56- 80, Mean= 67.89, STD deviation= 6.96 minutes). The length of intensive care unit (ICU) stays in hours (Range= 8-64, Mean = 35.87, STD deviation= 13.81 hours). The mechanical ventilation (MV) duration in hours (Range= 6-16, Mean = 11.11, STD deviation= 2.76 hours). The postoperative bleeding within 24 hours (Range= 135-365 ml, Mean = 248.67 ml, STD deviation= 36.34 ml). 10 patients of mAVR group needed a total of 13 units of packed RBC. The atrial fibrillation for the mAVR patients were 6 out of 45. Only one early mortality case was registered.

On the other hand, the descriptive statistics results cAVR patients Table III were observed as following; CPB duration (Range= 61-79 minutes, Mean = 69.80 minutes, STD deviation= 4.53 minutes). The aortic cross- clamping time (Range= 36-56 minutes, Mean = 46.64 minutes, STD deviation= 5.72 minutes). The ICU stay time for the cAVR patients (Range= 23-127 hours, Mean = 55.09 hours, STD deviation= 20.08 hours). The mechanical ventilation (MV) for the cAVR patients (Range= 6-20 hours, Mean = 12.82 hours, STD deviation= 3.62 hours). The postoperative bleeding within 24 hours for the, against that for the cAVR

patients (Range= 235-705 ml, Mean = 473.44 ml, STD deviation= 98.92ml). 16 patients of cAVR required 27 units of packed RBC. Only one early mortality case was registered.
The Factorial Analysis of Variance (ANOVA) examines the null hypothesis (H_0) in light of our research questions as following and as it is summarized in Table IV.

The Null Hypothesis 1 ($H_0$1): Cardiopulmonary bypass (CPB) will not differ between patients who underwent conventional sternotomy versus Mini-sternotomy
ANOVA analysis revealed that Cardiopulmonary bypass is significantly different between patients with differing Aortic Valve Replacement surgery techniques, F (1,88) = 590,34, $p < 0.05$, Partial Eta Squared (Partial $\eta 2$) = .870.
$H_0$2: Aortic clamping time will not differ between patients who underwent conventional sternotomy versus Mini-sternotomy
ANOVA analysis revealed that Aortic clamping time is significantly different between patients with differing Aortic Valve Replacement surgery techniques F (1,88) = 249.70, $p < 0.05$, Partial $\eta 2$ = .739.
$H_0$3: Mechanical ventilation time will not differ between patients who underwent Conventional sternotomy versus Mini-sternotomy.
ANOVA analysis revealed that Mechanical ventilation time is significantly different between patients with differing Aortic Valve Replacement surgery techniques F (1,88) = 6.350, $p < .05$, Partial $\eta 2$ = .067.
$H_0$4: Atrial fibrillation incidence will not differ between patients who underwent Conventional sternotomy versus Mini-sternotomy.
ANOVA analysis revealed that Atrial fibrillation incidence is not different between patients with differing Aortic Valve Replacement surgery techniques F (1,88) = .000, $p > .05$, Partial $\eta 2$ = .000.
$H_0$5: ICU stay will not differ between patients who underwent Conventional sternotomy versus Mini-sternotomy.
ANOVA analysis revealed that ICU time is significantly different between patients with differing Aortic Valve Replacement surgery techniques F (1,88) = 27, $p < .05$, Partial $\eta 2$ = .241.
$H_0$6: Post-operative bleeding within 24hr will not differ between patients who underwent Total sternotomy versus Mini-sternotomy.
ANOVA analysis revealed that Post-operative bleeding within 24hr is significantly different between patients with differing Aortic Valve Replacement surgery techniques F (1,88) = 204.70, $p < .05$, Partial $\eta 2$ = .699.
$H_0$7: The number of packed RBC units will not differ between patients who underwent Conventional sternotomy versus Mini-sternotomy.
ANOVA analysis revealed that significantly different between patients with differing Aortic Valve Replacement surgery techniques F (1,88) =3.68, $p > .05$, Partial $\eta 2$ = .040.
$H_0$8: Mortality within one month will not differ between patients who underwent Conventional sternotomy versus Mini-sternotomy.
ANOVA analysis revealed that mortality within one month is not different between patients with differing Aortic Valve Replacement surgery techniques F (1,88), $p > .05$, Partial $\eta 2$ = .000.

Characteristics	Conventional sternotomy	Mini-sternotomy
Age (years)	65 ± 12	67 ± 10
Female, n (%)	22 (48.8%)	25 (55.5%)
BMI (kg/cm2)	26.7	26.9
Diabetes, n (%)	26 (57.7%)	21 (46.6%)
Dyslipidemia, n (%)	19 (42.2%)	22 (48.8%)
Renal insufficiency, n (%)	2 (4.4%)	1 (2.2%)
Previous cerebrovascular accident, n (%)	3 (6.6%)	3 (6.6%)
Peripheral vascular disease, n (%)	5 (11.1%)	4 (8.8%)
Atrial fibrillation (%)	4 (8.8%)	5 (11.1%)
Aortic stenosis, n (%)	40 (88.88%)	42 (93.33%)
Aortic regurgitation, n (%)	5 (11.11%)	3 (6.66%)
Ejection fraction (%)	56 ± 9	55 ± 9
NYHA class III/IV (%)	35.8%	37%

Table I Summary of the preoperative patients' variables.

Outcomes	Minimum	Maximum	Mean	Median	Standard Deviation
Cardiopulmonary bypass (minutes)	82	114	98	98	6.32
Aortic clamping time (minutes)	56	80	67.89	68	6.96
Mechanical ventilation time (hours)	6	16	11.11	11	2.76
Atrial fibrillation incidence	0	1	.13	.00	.344
Intensive care unit stay duration (hours)	8	64	35.87	36	13.810
Post-operative bleeding within 24hr (ml)	135	365	248.67	250	36.344
Bleeding required transfusion	0	1	.22	.00	.420
Number of packed RBC unit	0	2	.29	.00	.589
Mortality within one month	0	1	.02	.00	.149

Table II Descriptive statistics Mini-sternotomy techniques

Outcomes	Minimum	Maximum	Mean	Median	Standard Deviation
Cardiopulmonary bypass (minutes)	61	79	69.80	70	4.536
Aortic clamping time (minutes)	36	56	46.64	47	5.72
Mechanical ventilation time (hours)	6	20	12.82	13	3.620
Atrial fibrillation incidence	0	1	.13	.00	.344

Intensive care unit stay duration (hours)	23	127	55.09	52	20.087
Post-operative bleeding within 24hr (ml)	235	705	473.44	485	98.92
Bleeding required transfusion	0	1	.36	.00	.484
Number of packed RBC unit	0	3	.60	.00	.915
Mortality within one month	0	1	.02	.00	.149

Table III Descriptive statistics Conventional sternotomy techniques

Source	Sum of Squares	Degree Freedom	F	p	Partial Eta Squared
Cardiopulmonary bypass	17892.9	1,88	590.3	.000	.870
Aortic clamping time	10154.84	1, 88	249.70	.000	.739
Mechanical ventilation time	65.87	1, 88	6.350	.014	.067
Atrial fibrillation incidence	.000	1,88	.000	1.000	.000
ICU	8313.61	1, 88	27.982	.000	.241
Post-operative bleeding within 24hr	1136813.61	1,88	204.70	.000	.699
Bleeding required transfusion	.400	1,88	1.949	.167	.022
Number of packed RBC unit	2.178	1, 88	3.682	.058	.040
Mortality within one month	.000	1, 88	.000	1.000	.000

Table IV The Factorial Analysis of Variance (ANOVA) Summary.

DISCUSSION

Despite the obvious benefit of the mini-sternotomy approach for AVR, even in the high-risk group (21, 22), we still need more robust evidence to support this conclusion.

Mini-sternotomy may reduce morbidity by limiting the invasiveness of the surgical intervention (11, 23-25). It is almost comparable to the lesser invasive techniques involved in the trans-catheter approaches, which include transapical transcatheter aortic valve implantation and transfemoral transcatheter aortic valve implantation in early mortality results (26).

The usage of computed tomography scans to evaluate the anatomical relationship among the intercostal spaces, ascending aorta, and aortic valve before the surgery, which we usually utilize to assess our patients for suitability of the lesser invasive procedure may also help in predicting the procedure's complexity (25).

A review of the extant literature indicates that some authors have highlighted the superiority of mAVR over cAVR (11, 27). The right ventricular dysfunction was less pronounced in the mini-sternotomy group than in the conventional sternotomy group (28). In redo AVR, the minimally invasive approach has been proven to be safe and effective with shorter hospital stays and better long-term survival (22, 29).

The introduction of a new surgical approach with the smaller incision is always challenged by the surgeon's abilities to learn and build new skills. A surgeon's technical experience and what fits the specific patient profile is what should determine the operative approach (9, 30). While some would prefer the partial upper sternotomy as an alternative approach in mAVR for obese patients (30), others use the right anterior mini-thoracotomy in patients undergoing isolated aortic valve surgery, which has also been proven to be safe (27, 31). One study assessing 900 patients (single-center) underwent minimally invasive AVR by mAVR. There were 12% reductions in (CPB) time and cross-clamp time with an increase in the surgeons' experience (32).

Our results indicate that both CPB time and aortic cross-clamp time were longer for mAVR than for cAVR, a finding consistent with most of the existing studies (11, 31, 33-34). One of the studies showed better outcomes in decreasing pump and clamp time by using adjuncts such as the automatic knot fastener (35). One of the significant advantages of mAVR identified in our study was the decreased transfusion requirement compared to the cAVR group, and this is consistent with the many studies that have reported less bleeding volume in the mAVR approach (10, 36). Along with the decreased transfusion requirement, blood loss within the first 24 hours after the surgery was also lower for the mAVR group.

As for the time needed for MV in the postoperative period, the mAVR approach had a shorter duration in all the studies that evaluated this issue (30, 36-38). In our study, the MV length was shorter in the mAVR approach than in the cAVR approach. The benefits of reducing the total hospital stay and the incidence of postoperative atrial fibrillation (as in the case of mAVR), especially in the high-volume centers, should also be considered as additional value (9). On the other hand, some questions remain unanswered concerning the superiority of the mini approach over conventional sternotomy for performing AVR as cost-effectiveness and quality-of-life assessment. One study has shown that mAVR had cost-effectiveness concerning hospital stay, faster recovery, and improved survival (39). In one small-sized study, there was no difference in the quality-of-life categories between the two surgical approaches (40). Anyhow, still we need to wait till randomized trials like QUALITY-AVR to answer this question (41).

Due to these clear benefits of mini-sternotomy, there was an early growing engagement in applying these techniques in Queen Alia Heart Institute since 1997 (42,43). Different Techniques were used such as upper mini-sternotomy (described earlier), right anterolateral mini-thoracotomy, and Tilted T Mini-sternotomy. Tilted T Mini-sternotomy also had a smooth learning curve and could attain conventional sternotomy merits with ordinary cardiac surgical tools and maneuvers with low postoperative morbidity and improves the quality of life (43).

Even though mAVR is gaining more popularity with time, the quality-of-life assessment and the 12-month observation favor transcatheter aortic valve replacement over invasive procedures (22). A recent meta-analysis by Sayed and et al. comparing minimally invasive surgery versus transcatheter aortic valve replacement (TAVR) demonstrated that: TAVR has shorter hospitalization stays and a lower incidence of acute kidney injury on the cost of increased midterm mortality and paravalvular leakage (44). As a result, these updated pieces of evidence will support the heart team to individualize the approach for each aortic valve replacement.

Study limitations:

This was a retrospective study, and it evaluated only a small number of patient cohorts; however, we think that our results will add to the already published literature addressing this subject.

Conclusions:

The mini-sternotomy for the AVR approach is a safe and effective strategy over and above its cosmetic advantages. No less important is the fact that it entails decreased transfusion requirement, ventilation time, ICU stays without compromising on the short- and long-term survival rates of the patients when compared with the cAVR approach.

REFERENCES

1. Musumeci L, Jacques N, Hego A, Nchimi A, Lancellotti P, Oury C. Prosthetic Aortic Valves: Challenges and Solutions. Front Cardiovasc Med. 2018;5:46. Published 2018 May 14.

2. Samiei N, Hakimi MR, Mirmesdagh Y, Peighambari MM, Alizadeh-Ghavidel A, Hosseini S. Surgical outcomes of heart valves replacement: A study of tertiary specialied cardiac center. ARYA Atheroscler. 2014;10(5):233-237

3. HARKEN DE, SOROFF HS, TAYLOR WJ, LEFEMINE AA, GUPTA SK, LUNZER S. Partial and complete prostheses in aortic insufficiency. J Thorac Cardiovasc Surg. 1960; 40:744-762.

4. Søndergaard L, Saraste A, Christersson C, Vahanian A. The year in cardiology 2017: valvular heart disease. Eur Heart J. 2018;39(8):650-657.

5. Cooley DA, Frazier OH. The past 50 years of cardiovascular surgery. Circulation. 2000;102(20 Suppl 4):IV87-IV93.

6. Rosengart TK, Feldman T, Borger MA, Vassiliades TA jr, Illinois AM, Hoercher K J, et al. Percutaneousus and minimally invasive valve procedures, a scientific statement from the AHA, ACCSA, CSA, C C C, FGTBIWG. Circulation. 2008; 117:1750–67.

7. Cohn LH, Adams DH, Couper GS, et al. Minimally invasive cardiac valve surgery improves patient satisfaction while reducing costs of cardiac valve replacement and repair. Ann Surg. 1997; 226:421–6; discussion 427–8.

8. Roberts DJ, Zygun DA, Ball CG, et al. Challenges and potential solutions to the evaluation, monitoring, and regulation of surgical innovations. BMC Surg. 2019;19(1):119. Published 2019 Aug 27.

9. Chang C, Raza S, Altarabsheh SE, et al. Minimally invasive approaches to surgical aortic valve replacement: a meta-analysis. Ann Thorac Surg. 2018; 106(6):1881–1889. doi:10.1016/j.athoracsur.2018.07.018

10. Bakir I, Casselman FP, Wellens F, Jeanmart H, De Geest R, Degrieck I, et al. Minimally invasive versus standard approach aortic valve replacement: a study in 506 patients. Ann Thorac Surg. 2006; 81(5):1599–604.

11. Aliahmed HMA, Karalius R, Valaika A, Grebelis A, Semėnienė P, Čypienė R. Efficacy of aortic valve replacement through full sternotomy and minimal invasion (Ministernotomy). Medicina (Kaunas). 2018 Apr 28; 54(2):26. doi:10.3390/medicina54020026

12. Malaisrie SC, Barnhart GR, Farivar RS, et al. Current era minimally invasive aortic valve replacement: techniques and practice. J Thorac Cardiovasc Surg. 2014;147(1):6-14.

13. Moscarelli M, Emmanuel S, Athanasiou T, Speziale G, Fattouch K, Casula R. The role of minimal access valve surgery in the elderly. A meta-analysis of observational studies. Int J Surg. 2016;33 Pt A:164-171.

14. Mohiuddin K, Swanson SJ. Maximizing the benefit of minimally invasive surgery. J Surg Oncol. 2013;108(5):315-319.

15. Rao PN, Kumar AS. Aortic valve replacement through right thoracotomy. Tex Heart Inst J. 1993; 20:307–8.

16. Cosgrove DM 3rd, Sabic JF. Minimally invasive approach for aortic valve operation. Ann Thorac Surg. 1996; 62:596–7.

17. Svensson LG. Minimal access sternotomy for valvular, aortic and coronary operation or reoperation. Ann Thorac Surg. 1997; 64:1501–3.

18. ElBardissi AW, Shekar P, Couper GS, et al. Minimally invasive aortic valve replacement in octogenarian, high-risk, transcatheter aortic valve implantation candidates. J Thorac Cardiovascular Surg. 2011; 141:328.

19. Gilmanov D, Bevilacqua S, Murzi M, et al. Minimally invasive and conventional aortic valve replacement: a propensity score analysis. Ann Thorac Surg. 2013; 96:837–43.

20. Mihaljevic T, Cohn LH, Unic D, et al. One thousand minimally invasive valve operations: early and late results. Ann Surg. 2004; 240:529–34; discussion 534.

21. Berretta P, Cefarelli M, Vessella W, et al. Ultra fast track surgery: a rapid deployment aortic valve replacement through a J-ministernotomy. J Vis Surg. 2018 May 8; 4:90. doi:10.21037/jovs.2018.04.14
22. Gosev I, Neely RC, Leacche M, et al. The impact of a minimally invasive approach on reoperative aortic valve replacement. J Heart Valve Dis. 2015; 24(2):181–186.
23. Tabata M, ZKaleyey P, Shekar S, Cohn LH. "Reoperative minimal access aortic valve surgery: minimal mediastinal dissection and minimal injury risk." Journal of Thoracic and Cardiovascular Surgery. 2008; 136(6):1564–1568.
24. Byrne JG, Adams DH, Couper GS, Rizzo RJ, Cohn LH, Aranki SF. "Minimally-invasive aortic root replacement," The Heart Surgery Forum. 1999; 2(4):326–329.
25. Elattar MA, Kaya A, Planken NR, et al. A computed tomography-based planning tool for predicting difficulty of minimally invasive aortic valve replacement. Interact Cardiovasc Thorac Surg. 2018; 27(4):505–511. doi:10.1093/icvts/ivy128
26. Furukawa N, Kuss O, Emmel E, et al. Minimally invasive versus transapical versus transfemoral aortic valve implantation: a one-to-one-to-one propensity score-matched analysis. J Thorac Cardiovasc Surg. 2018; 156(5):1825–1834. doi:10.1016/j.jtcvs.2018.04.104
27. Mikus E, Calvi S, Panzavolta M, et al. Right anterior mini-thoracotomy: a 'new gold standard' for aortic valve replacement? J Heart Valve Dis. 2015; 24(6):693–698.
28. Dalén M, Oliveira Da Silva C, Sartipy U, et al. Comparison of right ventricular function after ministernotomy and full sternotomy aortic valve replacement: a randomized study. Interact Cardiovasc Thorac Surg. 2018; 26(5):790–797. doi:10.1093/icvts/ivx422
29. Bonaros N, Özpeker C, Kofler M, et al. Minimally invasive redo-aortic valve replacement. Multimed Man Cardiothorac Surg. 2018 Jan 30; 2018:10. 1510/mmcts.2018.010. doi:10.1510/mmcts.2018.010
30. Welp HA, Herlemann I, Martens S, Deschka H. Outcomes of aortic valve replacement via partial upper sternotomy versus conventional aortic valve replacement in obese patients. Interact Cardiovasc Thorac Surg. 2018; 27(4):481–486. doi:10.1093/icvts/ivy083
31. Seitz M, Goldblatt J, Paul E, Marcus T, Larobina M, Yap CH. Minimally invasive aortic valve replacement via right anterior mini-thoracotomy: propensity matched initial experience. Heart Lung Circ. 2019; 28(2):320–326. doi:10.1016/j.hlc.2017.11.012
32. Johnston WF, Ailawadi G. Surgical management of minimally invasive aortic valve operations. Semin Cardiothorac Vasc Anesth. 2012; 16(1):41–51.
33. Sansone F, Punta G, Parisi F, Dato GM, Zingarelli E, Flocco R, et al. Right minithoracotomy versus full sternotomy for the aortic valve replacement: preliminary results. Heart Lung Circ. 2012; 21(3):169–73.
34. Pope NH, Ailawadi G. Minimally invasive valve surgery. J Cardiovasc Trans Res. 2014; 7(4):387–94.
35. Wang A, McCartney SL, Williams JB, et al. Use of adjuncts reduces cardiopulmonary bypass time during minimally invasive aortic valve replacement. J Heart Valve Dis. 2017; 26(2):155–160.
36. Gilmanov D, Bevilacqua S, Murzi M, Cerillo AG, Gasbarri T, Kallushi E, et al. Minimally invasive and conventional aortic valve replacement: a propensity score analysis. Ann Thorac Surg. 2013; 96(3):837–43.
37. Bonacchi M, Prifti E, Giunti G, Frati G, Sani G. Does ministernotomy improve postoperative outcome in aortic valve operation? A prospective randomized study. Ann Thorac Surg. 2002; 73(2):460–5.
38. Hiraoka A, Kuinose M, Chikazawa G, Totsugawa T, Katayama K, Yoshitaka H. Minimally invasive aortic valve replacement surgery: comparison of port-access and conventional standard approach. Circulation. 2011; 75(7):1656–60.
39. Nair SK, Sudarshan CD, Thorpe BS, et al. Mini-Stern Trial: A randomized trial comparing mini-sternotomy to full median sternotomy for aortic valve replacement. J Thorac Cardiovasc Surg. 2018; 156(6):2124–2132.e31. doi:10.1016/j.jtcvs.2018.05.057
40. Detter C, Deuse T, Boehm DH, Reichenspurner H, Reichart B. Midterm results and quality of life after minimally invasive vs. conventional aortic valve replacement. *Thorac Cardiovasc Surg*. 2002;50(6):337-341. doi:10.1055/s-2002-35743
41. Rodríguez-Caulo EA, Guijarro-Contreras A, Otero-Forero J, et al. Quality of life, satisfaction and outcomes after ministernotomy versus full sternotomy isolated aortic valve replacement (QUALITY-AVR):

study protocol for a randomised controlled trial. *Trials*. 2018;19(1):114. Published 2018 Feb 17. doi:10.1186/s13063-018-2486-x

42. Adnan Allaham ,Saed Jaber ,Walid Tarawneh ,Nabil Qaqish ,Hussam Nesheiwat , Minimally invasive valve surgery Queen Alia Heart Institute experience, J. Royal Med. Serv. 2005; 12 (2): 14-17

43. Ali M. Aburumman , Tilted T ministernotomy: a new approach in cardiac surgery, J. Royal Med. Serv. 2010; 17 (2): 61-69

44. Sayed A, Almotawally S, Wilson K, Munir M, Bendary A, Ramzy A, et al. Minimally invasive surgery versus transcatheter aortic valve replacement: a systematic review and meta-analysis. Open Heart. 2021 01;8(1):e001535.