Should less-invasive aortic valve replacement be avoided in patients with pulmonary dysfunction?

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Objective: In patients with pulmonary dysfunction, it is unclear whether a less-invasive approach for aortic valve replacement is well tolerated or even beneficial. We investigated whether a partial upper J-incision for aortic valve replacement leads to more favorable outcomes than a full sternotomy in patients with chronic lung disease by using forced expiratory volume in 1 second as a surrogate.

Methods: From January 1995 to July 2010, 6931 patients underwent primary isolated aortic valve replacement; 655 had forced expiratory volume in 1 second measured and expressed as percent of predicted (FEV1%; 368 via J-incision, 287 via full sternotomy). Postoperative outcomes were compared among 223 propensity-matched pairs.

Results: Patients diagnosed with chronic lung disease had longer median intensive care unit (41 vs 27 hours, $P = .001$) and postoperative (7.1 vs 6.1 days, $P < .0001$) lengths of stay than those without chronic lung disease. At normal values of FEV1%, little difference was observed in either of these times for J-incision versus full sternotomy; however, at progressively lower FEV1%, these times lengthened, with increasing benefit for J-incision. Among propensity-matched patients, other postoperative complications were similar. Early survival (93% vs 89% at 1 year, $P = .07$) was possibly higher in matched patients with J-incision, but late survival was similar ($P = .9$). Patients with FEV1% less than 50 who underwent J-incision had the greatest survival advantage, which persisted for 5 years.

Conclusions: In patients with preoperative respiratory dysfunction, a less-invasive partial upper J-incision for aortic valve replacement can lead to more favorable outcomes than a full sternotomy, including shorter intensive care unit and postoperative lengths of stay and better early survival, which are amplified with decreasing pulmonary function. (J Thorac Cardiovasc Surg 2014;147:355-61)

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Patients with severe respiratory dysfunction and chronic lung disease (CLD) are being seen more frequently, particularly for various types of transcatheter aortic valve replacement (AVR).¹ Whether these patients would tolerate or even benefit from a surgical AVR via a less-invasive J-incision rather than a full sternotomy is unknown. Even among our own group of surgeons, the less-invasive approach has not been adopted universally.

A paramedian incision for AVR was introduced in 1996²; subsequently, a partial upper J-incision (hereafter referred to simply as “J-incision”), introduced in 1997,³ has been gaining acceptance.²⁻⁵ We⁵ and others^{1,3,5-10} have reported that the J-incision has multiple benefits compared with a standard median sternotomy, including less surgical trauma, less pain, shorter ventilation time, and shorter intensive care unit (ICU) and hospital lengths of stay.²⁻¹⁰ Because of these possible advantages, a J-incision might

Abbreviations and Acronyms

AVR	= aortic valve replacement
CABG	= coronary artery bypass grafting
CLD	= chronic lung disease
FEV1	= forced expiratory volume in 1 second
FEV1%	= forced expiratory volume in 1 second, percent of predicted
ICU	= intensive care unit

be beneficial for high-risk patients, such as those with pulmonary dysfunction, a well-established risk factor for mortality and morbidity after cardiac surgery.^{5,11,12}

The J-incision may stabilize the sternum and thoracic cage, resulting in better postoperative pulmonary function.³⁻⁵ Furthermore, it is believed that less spreading of the incision, not interfering with the diaphragm, and less tissue dissection might facilitate earlier postoperative respiratory recovery.^{5,13} Yet these perceived benefits have not been studied in the specific high-risk group of patients with pulmonary dysfunction.^{3,4,6-14}

Such a study is challenging because pulmonary dysfunction comprises a broad spectrum of lung diseases and is complex to define. Spirometry is the most common pulmonary function test used to assess severity and operative risks in these patients.¹⁵ It is not influenced by observer bias and provides markers for degree of lung function impairment. Therefore, we investigated whether a J-incision for AVR leads to more favorable outcomes in patients with pulmonary dysfunction, using forced expiratory volume in 1 second, percent of predicted (FEV1%), as a surrogate.

PATIENTS AND METHODS**Patients**

From January 1995 to July 2010, 6931 patients underwent primary isolated AVR, of whom 655 had preoperative spirometry data available (J-incision in 368 and full sternotomy in 287). Patients undergoing concomitant mitral valve surgery or coronary artery bypass grafting (CABG) were excluded, as were those with active endocarditis. Mean age was 68 ± 13 years, and 54% were men.

Data

Data were retrieved from the prospective Cardiovascular Information Registry, supplemented with information from the Echocardiography database. Preoperative spirometry data were obtained from the institution's prospectively recorded Pulmonary Function Laboratory database. Preoperative forced expiratory volume in 1 second (FEV1) and forced vital capacity values were normalized to percent of predicted by the National Health and Nutrition Examination Survey algorithm.¹⁶ All data were approved for use in research by the Institutional Review Board, with patient consent waived.

Surgical Technique

Conventional general anesthesia was used in all patients regardless of surgical approach. Patients who underwent less-invasive J-incision had an 8- to 10-cm skin incision. The upper sternum was divided in the midline,

and this sternotomy was extended into the right fourth intercostal space forming a J.^{3,4} The diaphragm was not interfered with, and spreading the incision was limited to approximately 5 cm, minimizing tension and flexing of the posterior rib attachments to the vertebral bodies. Approach to the aortic valve was via an oblique aortotomy carried into the noncoronary cusp or a transverse aortotomy above the sinutubular junction, and choice of valve type was at the discretion of the surgeon. AVR was then carried out according to the surgeon's standard technique.

Vacuum-assisted cardiopulmonary bypass with central cannulation was used in all patients. Intraoperative transfusions, anesthetic technique, and timing of extubation were at the anesthesiologists' and critical care team's discretion. Intraoperative and postoperative transfusions were not driven by protocolized transfusion triggers, except that Cleveland Clinic has long advocated blood-conservation practices.

Outcomes

Outcomes assessed included intraoperative support (myocardial ischemic time, cardiopulmonary bypass time), postoperative in-hospital mortality and morbidity (defined in accordance with the Society of Thoracic Surgeons National Database: http://www.ctsnet.org/file/rptDataSpecifications252_1_ForVendorsPGS.pdf), blood product use, time to extubation, ICU and postoperative lengths of stay, and long-term survival.

Survival was assessed by active follow-up at 2 years and then every 5 years using an Institutional Review Board–approved questionnaire with patient consent required. Vital status was supplemented with data from the Social Security Death Master File with a censoring date of February 15, 2011. A total of 2423 patient-years of combined active and passive follow-up for vital status were available for analysis, with a median follow-up of 2.7 years; 25% of survivors were followed more than 6.1 years, and 10% were followed more than 9.2 years. Thus, survival curves are truncated at 10 years. The seemingly short median follow-up is caused by a combination of an escalating volume of AVRs in recent years⁵ and increased use of preoperative spirometry (Figure E1).

Data Analysis

All analyses were performed using SAS statistical software (v9.1; SAS Institute Inc, Cary, NC).

Spirometry and Chronic Lung Disease

Trends in spirometry values according to clinical diagnosis of CLD were estimated by logistic regression analysis, as were factors associated with performing preoperative spirometry.

Factors Associated With Surgical Approach

A number of patient characteristics differed between those receiving a less-invasive J-incision and those undergoing full sternotomy, including spirometry data (Table 1). Logistic regression analysis was used to identify statistically significant preoperative differences. A parsimonious model was developed using bagging.^{17,18} Briefly, a patient is selected at random to begin building a new data set, and this random selection process is repeated until the new data set is the same size as the original. On average, approximately one third of patients are not selected, and therefore a number of patients are duplicated. This is known as a bootstrap sample; 1000 such bootstrap data sets were built. Each was then analyzed by automated stepwise regression with a *P* value criterion to retain of .05 using the candidate risk factors listed in Appendix E1. This resulted in 1000 regression models. These models were then aggregated by counting the frequency of occurrence of variables in the 1000 models. We consolidated counts of closely correlated variables such as linearizing transformations of scale. We then selected variables for the final model if they appeared in 50% or more of the analyses (a measure of reliability).

TABLE 1. Patient characteristics and operative details by surgical approach

Variable	All patients				Propensity-matched patients			
	J-incision (n = 368)		Full (n = 287)		J-incision (n = 223)		Full (n = 223)	
	n*	No. (%) or mean ± SD	n*	No. (%) or mean ± SD	n*	No. (%) or mean ± SD	n*	No. (%) or mean ± SD
Demography								
Women	368	177 (48)	287	126 (44)	223	105 (47)	223	104 (47)
Age (y)	368	69 ± 12	287	67 ± 13	223	67 ± 13	223	68 ± 13
BMI (kg·m ⁻²)	349	30 ± 7.2	261	30 ± 8.0	208	30 ± 7.6	203	31 ± 8.0
NYHA functional class	288		225		174		172	
I		54 (19)		36 (16)		32 (18)		31 (18)
II		145 (50)		114 (51)		89 (51)		85 (49)
III		80 (28)		67 (30)		45 (26)		52 (30)
IV		9 (3.1)		8 (3.6)		8 (4.6)		4 (2.3)
Indication for operation	366		285		222		222	
Degenerative		360 (98)		268 (94)		216 (97)		209 (94)
Other		6 (1.6)		17 (6.0)		6 (2.7)		13 (5.8)
Cardiac comorbidity								
LVEF (%)	358	56 ± 8.7	281	52 ± 14	217	56 ± 9.0	218	55 ± 11
Aortic valve area (cm ²)	326	0.7 ± 0.2	226	0.7 ± 0.4	192	0.7 ± 0.2	184	0.7 ± 0.2
Aortic valve gradient (mm Hg)								
Mean	334	48 ± 16	245	47 ± 18	197	48 ± 16	196	47 ± 17
Peak	334	82 ± 23	245	80 ± 29	197	82 ± 24	196	81 ± 28
LV mass index (g·m ⁻²)	327	118 ± 36	240	136 ± 45	193	125 ± 38	187	126 ± 39
LA volume index (mL·m ⁻²)	316	18 ± 10	229	21 ± 11	184	19 ± 11	180	19 ± 11
Tricuspid regurgitation more than moderate	343	43 (12)	271	24 (8.8)	214	25 (12)	209	16 (7.6)
Atrial fibrillation/flutter	346	17 (4.9)	257	7 (2.7)	207	9 (4.3)	199	7 (3.5)
Noncardiac comorbidity								
Hypertension	368	255 (69)	287	200 (70)	223	157 (70)	223	157 (70)
CLD	368	133 (36)	287	117 (41)	223	86 (39)	223	88 (39)
Past or current smoking	367	238 (65)	286	183 (64)	223	141 (63)	223	149 (67)
FEV1%	368	84 ± 23	287	78 ± 21	223	80 ± 21	223	80 ± 21
FVC (% of predicted)	368	89 ± 20	287	81 ± 19	223	85 ± 20	223	83 ± 19
FEV1/FVC	368	70 ± 12	287	72 ± 11	223	71 ± 12	223	72 ± 11

SD, Standard deviation; BMI, body mass index; NYHA, New York Heart Association; LVEF, left ventricular ejection fraction; LV, left ventricle; LA, left atrial; CLD, chronic lung disease; FEV1%, forced expiratory volume in 1 second, percent of predicted; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 second. *Number of patients with data available.

Propensity Score Development and Use

To reduce the influence of selection bias for surgical approach, we used propensity matching.¹⁹ After establishing the parsimonious model for approach (Table E1), we added other variables, identified in Appendix E1, representing groups of patient factors that might be related to unrecorded selection factors (saturated model). A propensity score was then calculated for each patient by solving the saturated model for the probability of undergoing a full sternotomy versus a J-incision.

By using only the propensity score, 223 patients (78%) who received a J-incision were matched to patients who received a full sternotomy using a greedy matching strategy. These matched patients spanned the majority of patients (Figure E2, A), although patients with extreme propensity scores (strongly favoring J-incision or strongly favoring full sternotomy) represent unmatched patients whose propensity scores deviated more than 0.2 from those of patients receiving a full sternotomy. The result was 2 groups of patients well matched for characteristics (Table 1 and Figure E2, B). In addition, because the number of events was insufficient to perform an extensive multivariable analysis, the propensity score itself was used additionally as a risk-adjustment factor for analyses of survival.²⁰

Managing Missing Covariable Data

We used 5-fold multiple imputation using a Markov Chain Monte Carlo technique to impute missing covariable values in multivariable analyses (SAS PROC MI, SAS Institute, Inc). The first imputation data set was used for model development, followed by fitting the final model to each of the other 4 data sets and then aggregating the results (SAS PROC MIANALYZE, SAS Institute, Inc).

Comparisons

Continuous variables were compared using the Wilcoxon rank-sum test. Categorical variables were compared using the chi-square test or Fisher exact test when frequency was less than 5.

The unadjusted relationship of FEV1% and intubation time, ICU length of stay, and postoperative length of stay was characterized semiparametrically using spline smoothing, stratified by surgical approach (SPlus v8.04, 2007, Insightful Corp, Seattle, Wash). The resulting smoothed curves for these outcomes were superimposed on box plots for 4 equal intervals according to approach. Each relation was adjusted for preoperative variables (Appendix E1) using linear regression and bagging as described earlier.

Nonparametric survival estimates were obtained by the Kaplan–Meier method and parametrically by a multiphase hazard model.²¹ (For additional details, see <http://my.clevelandclinic.org/professionals/software/hazard/default.aspx>). The parametric model was used to resolve a number of phases of instantaneous risk of death (hazard function) and to estimate shaping parameters. Risk factors for each hazard phase were identified simultaneously using bagging, as described previously.

Presentation

Continuous variables are summarized as mean $\pm$ standard deviation and as 15th, 50th (median), and 85th percentiles for skewed data distributions. Categorical variables are summarized by frequencies and percentages. Parametric estimates are accompanied by asymmetric 68% confidence bands, comparable to ± 1 standard error.

RESULTS

Preoperative Spirometry and History of Chronic Lung Disease

Preoperative spirometry was performed in only 10% to 15% of patients before 2006, but since then that proportion has increased to 30% to 45% (Figure E1). Spirometry was performed preferentially in patients with a history of smoking, clinical diagnosis of CLD, or higher risk (Tables E2 and E3).

Lower spirometry values were progressively more strongly associated with clinical history of CLD (Figure E3). FEV1% was more discriminating than forced vital capacity percent of predicted (lung-diffusing capacity was available for only a minority of patients). Lower FEV1% also was associated with older age, history of smoking, heart failure, atrial fibrillation, kidney dysfunction, smaller aortic valve area, and lower ejection fraction (Table E4).

Preoperative Spirometry and Surgical Approach

Preoperative spirometry was strongly related to surgical approach (Table 1), with full sternotomy apparently preferred for patients with poorer respiratory function. Full sternotomy also was more common in patients with heart failure, lower ejection fraction, impaired hepatic function, and greater left ventricular mass (Table E1).

Intubation Time

Preoperative FEV1% was not correlated with duration of intubation, either unadjusted ($P = .2$) or adjusted for preoperative variables ($P = .4$) (Figure 1, A). Patients in the full sternotomy group had a higher occurrence of respiratory insufficiency (intubated >24 hours) than the propensity-matched J-incision group (10% vs 5.1%, $P = .06$; Table 2), although mean duration of intubation was similar (15 ± 6.3 hours vs 14 ± 6.5 hours, respectively, $P = .4$; Table 2).

Length of Intensive Care Unit Stay

Patients with lower preoperative FEV1% had more prolonged ICU stays ($P = .0002$ unadjusted, $P < .0001$ adjusted

FIGURE 1. Relationship of FEV1% to intubation time and ICU and postoperative (*Post-Op*) lengths of stay. Box plots show 15th, 25th, 50th, 75th, and 85th percentiles of data points for 4 equal intervals of FEV1% values stratified by surgical approach. Solid lines represent spline fits for the J-incision group, and dashed lines represent fits for the full sternotomy group. A, FEV1% and intubation time (hours). B, FEV1% and ICU stay. C, FEV1% and postoperative stay. FEV1, Forced expiratory volume in 1 second; ICU, intensive care unit; LOS, length of stay.

TABLE 2. In-hospital outcomes by surgical approach, overall and in propensity-matched patients*

Outcome	Overall				Propensity-matched				
	J-incision (n = 368)		Full sternotomy (n = 287)		P	J-incision (n = 223)		Full sternotomy (n = 223)	
	No.	%	No.	%		No.	%	No.	%
Intubation time (h)†	14 ± 6.4		15 ± 6.2		.3	14 ± 6.5		15 ± 6.3	.4
ICU length of stay (h)‡	22/27/78		24/31/120		.0007	22/26/79		24/29/96	.02
Postoperative length of stay (d)‡	5/6/10		5/7/12		<.0001	5/6/10		5/7/11	.01
Respiratory insufficiency	16	5.3	30	14	.0005	9	5.1	18	10
Stroke	3	0.82	2	0.69	.9	2	0.89	2	0.89
Renal failure	9	2.4	16	5.6	.04	6	2.7	9	4.0
Myocardial infarction	0	0	0	0	—	0	0	0	0
Deep sternal wound infection	2	0.54	2	0.69	.8	2	0.89	0	0
Sepsis/septicemia	4	1.1	6	2.1	.3	4	1.8	4	1.8
Return to OR for bleeding	11	3.0	11	3.8	.6	7	3.1	9	4.0
Death	2	0.54	6	2.1	.07	2	0.89	4	1.8

ICU, Intensive care unit; OR, operating room. *Morbidities as defined by and submitted to the Society of Thoracic Surgeons Adult Cardiac National Database. †Mean ± standard deviation. ‡15th/50th/85th percentiles.

for preoperative variables; Figure 1, B). Length of ICU stay was longer in the full sternotomy group (median, 29 hours) than in the propensity-matched J-incision group (median, 26 hours; *P* = .02; Table 2).

Length of Postoperative Stay

Patients with lower preoperative FEV1% had more prolonged postoperative stays (*P* < .0001 unadjusted and adjusted for preoperative variables; Figure 1, C). Length of postoperative stay was longer in the full sternotomy group (median, 7 days) than in the matched J-incision group (median, 6 days; *P* = .01; Table 2).

Hospital Mortality and Complications

Among propensity-matched patients, hospital mortality (1.8% full sternotomy vs 0.89% J-incision) and morbidity were similar for patients with a full sternotomy and those with a J-incision (Table 2).

Survival

Patients with lower preoperative FEV1% had lower propensity-adjusted survival (Figure 2, A and Table 3). This was particularly apparent in the full sternotomy group, with confidence bands separating below an FEV1% of approximately 50. However, by 5 years, these curves converged (Figure 2, B). Unadjusted survival was lower in the early hazard phase after full sternotomy than after J-incision; survival estimates at 6 months and 1, 5, and 10 years were 89%, 87%, 73%, and 48% in the full sternotomy group versus 95%, 94%, 80%, and 55% in the J-incision group, respectively (Figure E4). Risk-adjusted survival was more similar (Figure E5), with the important interaction of approach with FEV1% as noted in Table 3 and Figure 2. Thus, lower preoperative FEV1% was an incremental risk factor in the early hazard phase and both lower

FEV1% and full sternotomy in the late hazard phase, with J-incision protective.

DISCUSSION

Principal Findings

This study has shown that with increasingly poor pulmonary function, as measured by FEV1%, patients with CLD derive a greater benefit from undergoing a less-invasive J-incision for AVR than AVR performed through a full sternotomy. This is reflected in the results showing that postoperative respiratory insufficiency, defined as intubation for more than 24 hours, was twice as high for full sternotomy, and ICU and postoperative lengths of stay were longer, particularly in patients with lower FEV1%. Furthermore, hospital mortality was twice as high for full sternotomy, and later survival was worse, especially among patients with low FEV1%. Indeed, the lower the FEV1%, the better the 1-year survival for those undergoing a less-invasive J-incision compared with those undergoing full sternotomy. Even to 10 years, patients receiving a J-incision maintained an approximate survival advantage of 8%, both unadjusted and after propensity matching. Thus, this article confirms for the first time the theoretic advantage of less interference with respiratory function using the less-invasive approach, and this is reflected in better respiratory outcomes and survival, particularly in high-risk patients with poor respiratory function.

Clinical Implications

Pulmonary dysfunction in patients with CLD is a well-documented risk factor for morbidity and mortality after cardiac surgery. Analyses of large cardiac registries have reported increased odds of in-hospital mortality by ratios of 1.4 to 1.6 among patients with versus without CLD.²²⁻²⁶ Reduction of lung function postoperatively is influenced

FIGURE 2. Nomograms of 1- and 5-year risk-adjusted mortality according to preoperative FEV1% stratified by approach. These nomograms represent solutions to the multivariable equation found in Table 3. A, Predicted 1-year mortality. B, Predicted 5-year mortality. FEV1, Forced expiratory volume in 1 second.

not only by use of extracorporeal circulation but also by length of the sternal incision.^{13,22,23} Trauma to the sternum, use of internal thoracic artery for bypass grafting, opening the pleura, and placing chest tubes may affect postoperative pulmonary function, especially in patients with poor pulmonary reserve.²⁷

Thus, surgical strategies should be modified in patients with pulmonary dysfunction. Use of a J-incision may stabilize the sternum and thoracic cage, resulting in better postoperative pulmonary function and ability to cough and breathe.^{3,4,6,13} This advantage may be the result of less surgical dissection, less spreading of the sternum, and minimizing tension on the posterior rib head and costovertebral ligaments, because the chest wall is not opened like a trap door. Further, there is no interference with the diaphragm or dissection along it. Also, with less chest wall pain, patients may have less splinting of the chest and thus breathe more deeply. Meta-analysis has shown shorter intubation times after the J-incision approach.⁹

We showed previously in a propensity-matched comparison that a substantially higher proportion of matched

TABLE 3. Incremental risk factors for death after aortic valve replacement, with propensity for full sternotomy forced into model*

Factor	Coefficient $\pm$ SE	P
Early hazard phase		
Lower FEV1%†	1.13 $\pm$ 0.30	.0002
J-incision	0.37 $\pm$ 0.85	.7
J-incision/FEV1% interaction	0.69 $\pm$ 0.63	.3
Propensity for full sternotomy	0.94 $\pm$ 0.71	.18
Late hazard phase		
Lower FEV1%‡	1.31 $\pm$ 0.48	.007
J-incision	5.61 $\pm$ 2.95	.06
Full sternotomy/FEV1% interaction	1.34 $\pm$ 0.70	.06
Propensity for J-incision	0.23 $\pm$ 0.62	.7

SE, Standard error; FEV1%, forced expiratory volume in 1 second, percent of predicted. *Adjusted for age, body mass index, New York Heart Association functional class, aortic valve peak gradient, tricuspid valve regurgitation, peripheral arterial disease, previous stroke, diabetes, and blood urea nitrogen. †(FEV1%/81)⁻¹, inverse transformation. ‡Ln(FEV1%), logarithmic transformation.

patients were extubated in the operating room after a J-incision than after full sternotomy (12% vs 1.6%, $P < .0001$).⁵ Median time to extubation was also shorter (5.2 hours [confidence limit, 2.5-12] vs 6.9 hours [confidence limit, 3.6-21], $P < .0001$). FEV1% was higher immediately after extubation in the J-incision group, with the difference narrowing during the first 36 hours after surgery. Of note, risk of respiratory failure was lower with the J-incision ($P = .01$).

These results confirm the need to modify our surgical strategies for patients with severe pulmonary dysfunction who are at high risk for postoperative morbidity and mortality after full sternotomy. This risk has been demonstrated repeatedly in patients undergoing CABG. Canver and colleagues²⁴ identified preoperative FEV1% as an important predictor of 5-year survival in patients with CLD undergoing CABG. Preoperative FEV1 of less than 1.25 carried a 7-fold higher risk of death during follow-up, with 9-year survival of 42% versus 76% for those with higher FEV1. Other studies have shown similar in-hospital mortality for patients with mild to moderate CLD and worse outcomes among those with severe CLD.²⁵ Fuster and colleagues²⁶ have demonstrated that operative mortality after CABG is related to severity of CLD; mortality was 0.4% to 0.9% in patients with FEV1% more than 60%, but 11% for FEV1% of 40% to 59% and 54% for FEV1% less than 40%.

Clinical implications are that the less-invasive J-incision should be encouraged rather than avoided for high-risk patients with pulmonary disease. We therefore recommend this approach for these patients.

Study Limitations

Investigation of the influence of chronic obstructive pulmonary disease or CLD on survival and morbidity after

cardiac surgery is confounded by definitions and ability to measure degree of dysfunction. We chose to use FEV1% as a surrogate, fully aware that other tests, such as lung diffusion capacity testing and arterial blood gases, may have added to the study's predictive abilities. However, these tests were not routinely available. Ideally, a randomized trial between the less-invasive J-incision and full sternotomy should be performed in high-risk patients with severe pulmonary dysfunction. On the basis of our experience with this population, however, including the transcatheter AVR trials,¹ we do not have equipoise for such a trial.

We used propensity matching to compare patients receiving J-incision with those undergoing full sternotomy. However, propensity methods address only that portion of the spectrum for which heterogeneity in practice is discovered (virtual equipoise). As with randomized trials, it is tempting to extrapolate beyond the confines of the overlapping portions of the spectrum. Furthermore, at both extremes of the spectrum, surgeons at the Cleveland Clinic during the period of this study systematically performed J-incision or full sternotomy for AVR. We acknowledge that selection bias cannot be completely reversed by propensity-based methods and, in this study, cannot completely overcome distinct surgeon preferences, although we attempted to adjust for these. Treatment was not masked, and this could have influenced ICU critical care management to an unmeasurable extent.

This is also a single-institution study conducted at a high-volume center, which may have decreased the differences in outcomes between the 2 strategies and may limit its generalizability. Nevertheless, time to extubation and spirometry values would largely have been uninfluenced by potential surgeon biases because these were determined or routinely collected by respiratory therapists, anesthesiologists, interventionists, or nurses.

CONCLUSIONS

For patients with severe respiratory dysfunction, a less-invasive partial upper J-incision for AVR can lead to more favorable outcomes than full sternotomy, including shorter ICU and postoperative lengths of stay and better early survival, which are amplified with decreasing pulmonary function.

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APPENDIX E1. Variables used in analyses

Demographics

Age (y), * sex, * race, * height (cm), weight (kg), body surface area (m^2), body mass index ($\text{kg} \cdot \text{m}^{-2}$)*

Preoperative symptoms

NYHA functional class (I-IV)*

Cardiac comorbidity

Complete heart block, * ventricular arrhythmia, * chronic heart failure, * previous cardiac operation

Noncardiac comorbidity

Hypertension, * peripheral arterial disease, * diabetes, * stroke, * smoking*

Laboratory medicine

Blood urea nitrogen ($\text{mg} \cdot \text{dL}^{-1}$), * total cholesterol ($\text{mg} \cdot \text{dL}^{-1}$), * low-density lipoprotein ($\text{mg} \cdot \text{dL}^{-1}$), * high-density lipoprotein ($\text{mg} \cdot \text{dL}^{-1}$), * creatinine ($\text{mg} \cdot \text{dL}^{-1}$), * hematocrit (%), * bilirubin ($\text{mg} \cdot \text{dL}^{-1}$), * triglycerides ($\text{mg} \cdot \text{dL}^{-1}$)

Valve pathology

AV regurgitation, AV stenosis, * mitral valve regurgitation, tricuspid valve regurgitation, AV native

AV etiology

Rheumatic, degenerative

LV size

LV end-diastolic volume (mL), * LV end-systolic volume (mL), * LV diastolic diameter (cm), LV systolic diameter (cm), LV mass (g), * posterior wall thickness (cm), septal thickness (cm)

LV function

Myocardial infarction, * ejection fraction (%), * fractional shortening (%)*

Left atria

Left atrial diameter (cm), left atrial volume (mL), * AV systolic area (cm^2), * AV mean gradient (mm Hg), * AV peak gradient (mm Hg)*

Spirometry

FEV1, percent of predicted*, FVC, percent of predicted; FEV1/FVC ratio*

Experience

Years since January 1, 1995*

NYHA, New York Heart Association; AV, aortic valve; LV, left ventricular; FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity. *Variables included in propensity model.

FIGURE E1. Preoperative spirometry testing over time, 1997 to 2010 (n = 2619, with 655 patients undergoing testing).

FIGURE E2. Propensity score matching for J-incision versus full sternotomy. A, Mirrored histogram of distribution of propensity scores for J-incision versus full sternotomy groups. Darkened area represents matched patient pairs. B, Covariable balance for selected variables before (closed triangles) and after (closed squares) propensity matching, expressed as standardized difference.¹ NYHA, New York Heart Association; FEV1, forced expiratory volume in 1 second; FEV1%, forced expiratory volume in 1 second, percent of predicted; FVC, forced vital capacity; HDL, high-density lipoprotein; LV, left ventricular; PAD, peripheral arterial disease. 1. Austin PC, Mamdani MM. A comparison of propensity score methods: a case-study estimating the effectiveness of post-AMI statin use. *Stat Med*. 2006;25:2084-106.

FIGURE E3. Relationship of clinical diagnosis of CLD to spirometry values. Closed circles represent percentages in grouped data, and solid line with its 68% confidence limits is a univariable logistic regression estimate of the trend. A, FEV1%. B, FVC expressed as percent of predicted. C, FEV1/FVC. CLD, Chronic lung disease; FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity.

ACD

FIGURE E4. Unadjusted survival after aortic valve procedure stratified by approach. Each symbol represents a death positioned on a vertical axis by the Kaplan–Meier estimator, vertical bars are confidence limits equivalent to 1 standard error (SE), and numbers in parentheses are patients still alive and traced at 1, 3, 5, and 10 years. Solid lines are parametric survival estimates enclosed within dashed 68% confidence bands equivalent to ± 1 SE.

A

B

FIGURE E5. Mortality after AVR, stratified by approach (matched patient pairs). A, Survival. Each symbol represents a death positioned on a vertical axis by the Kaplan–Meier estimator, vertical bars are confidence limits equivalent to 1 standard error, and numbers in parentheses are patients still alive and traced at 1, 3, 5, and 10 years. Solid lines are parametric survival estimates enclosed within dashed 68% confidence bands equivalent to ± 1 standard error. B, Hazard function. Parametric estimates (solid lines) are enclosed within dashed confidence bands equivalent to ± 1 standard error. AVR, Aortic valve replacement.

TABLE E1. Variables associated with surgical approach: Full sternotomy versus J-incision

Variable	Coefficient ± SE	P	Reliability (%) [*]
Factors favoring full sternotomy			
Spirometry			
Lower FEV1% [†]	−0.62 ± 0.17	.0003	94
Higher FEV1/FVC [‡]	1.6 ± 0.33	<.0001	94
Greater left ventricular mass [§]	0.0056 ± 0.0024	.02	83
Heart failure	0.56 ± 0.21	.008	88
Peripheral arterial disease	0.77 ± 0.32	.02	72
Higher bilirubin	0.47 ± 0.25	.06	52
Factor favoring J-incision			
Higher EF	0.67 ± 0.27	.01	85

C-statistic of this parsimonious model is 0.701. *SE*, Standard error; *FEV1*%, forced expiratory volume in 1 second, percent of predicted; *FEV1*, forced expiratory volume in 1 second; *FVC*, forced vital capacity; *EF*, ejection fraction. ^{*}Percent of times factor appeared in 1000 bootstrap models. [†]Exp(FEV1%/81), exponential transformation. [‡](FEV1%/FVC/72)², squared transformation. [§]Indexed by body surface area. ^{||}(EF/52)^{−1}, inverse transformation.

TABLE E2. Patient characteristics and operative details stratified by pulmonary function test (total n = 2619)

Variable	Pulmonary function test (n = 655)		No pulmonary function test (n = 1964)		P
	n*	No. (%) or mean ± SD	n*	No. (%) or mean ± SD	
Demography					
Women	655	303 (46)	1964	758 (39)	.0005
Age (y)	655	68 ± 13	1964	64 ± 14	<.0001
BMI (kg·m ⁻²)	610	30 ± 7.6	1699	29 ± 6.8	.0002
NYHA functional class	513		1452		<.0001
I		90 (18)		379 (26)	
II		259 (50)		788 (54)	
III		147 (29)		249 (17)	
IV		17 (3.3)		36 (2.5)	
Indication for operation					
Degenerative	651	628 (96)	1953	1828 (94)	.006
Other	651	23 (3.5)	1953	125 (6.4)	.006
Cardiac comorbidity					
LVEF (%)	639	55 ± 11	1834	55 ± 10	.7
Aortic valve area (cm ²)	552	0.71 ± 0.27	1486	0.71 ± 0.25	.5
Aortic valve gradient (mm Hg)					
Mean	579	47 ± 16	1588	50 ± 18	.001
Peak	579	81 ± 26	1593	84 ± 28	.02
LV mass index (g·m ⁻²)	567	126 ± 41	1547	134 ± 47	<.0001
LA volume index (mL·m ⁻²)	545	19 ± 11	1428	19 ± 9.9	.5
Tricuspid regurgitation more than moderate	614	17 (2.8)	1840	24 (1.3)	.01
Atrial fibrillation/flutter	603	24 (4.0)	1678	39 (2.3)	.03
Noncardiac comorbidity					
Hypertension	655	455 (69)	1964	1192 (61)	<.0001
CLD	655	250 (38)	1964	104 (5.3)	<.0001
Past or current smoking	653	421 (64)	1945	869 (45)	<.0001
FEV1%	655	81 ± 22	—	—	—
FVC (% of predicted)	655	86 ± 20	—	—	—
FEV1/FVC	655	71 ± 12	—	—	—

SD, Standard deviation; *BMI*, body mass index; *NYHA*, New York Heart Association; *LVEF*, left ventricular ejection fraction; *LV*, left ventricle; *LA*, left atrial; *CLD*, chronic lung disease; *FEV1*%, forced expiratory volume in 1 second, percent of predicted; *FEV1*, forced expiratory volume in 1 second; *FVC*, forced vital capacity. ^{*}Number of patients with data available.

TABLE E3. Factors related to obtaining spirometry before aortic valve surgery (n = 2619; 655 patients with testing)

Variables associated with preoperative spirometry testing	Coefficient ± SE	P	Reliability (%)*
Female	0.33 ± 0.11	.002	60
History of CLD	2.37 ± 0.14	<.0001	100
History of recent smoking	0.77 ± 0.11	<.0001	100
Preoperative atrial fibrillation	0.78 ± 0.31	.01	56
Higher triglycerides (mg·dL ⁻¹)	0.32 ± 0.11	.003	52
Lower preoperative AV mean gradient (mm Hg)	0.007 ± 0.003	.04	67
Higher NYHA functional class	0.28 ± 0.08	.0006	84
More recent date of operation	0.18 ± 0.01	.02	100

C statistic = 0.799. SE, Standard error; CLD, chronic lung disease; AV, aortic valve; NYHA, New York Heart Association. *Percent of times factor appeared in 1000 bootstrap models.

TABLE E4. Variables associated with higher preoperative forced expiratory volume in 1 second, percent of predicted

Variable	Coefficient ± SE	P	Reliability (%)*
Higher FEV1%			
Male	3.5 ± 1.6	.03	60
Older age			
Exp(age)	97 ± 21	<.0001	100
Age ²	-132 ± 30	<.0001	100
Higher preoperative creatinine†	-3.2 ± 1.2	.008	52
Higher HDL	0.12 ± 0.05	.02	53
Greater aortic valve area	4.6 ± 2.3	.04	79
Higher LVEF‡	4.8 ± 2.0	.02	57
Lower FEV1%			
History of CLD	-24 ± 1.4	<.0001	100
History of smoking or recent smoker	-3.7 ± 1.5	.01	100
History of heart failure	-4.7 ± 1.8	.007	86
Preoperative atrial fibrillation	-12 ± 3.6	.001	86
Lower preoperative BUN§	-6.5 ± 2.0	.002	64

Average R^2 of this model is 0.436. SE, Standard error; FEV1%, forced expiratory volume in 1 second, percent of predicted; HDL, high-density lipoprotein; LVEF, left ventricular ejection fraction; CLD, chronic lung disease; BUN, blood urea nitrogen. *Percent of times factor appeared in 1000 bootstrap models. †(1/creatinine)², inverse squared transformation. ‡(EF/52)², squared transformation. §Ln(BUN), logarithmic transformation.