Vacuum-assisted venous return reduces blood usage

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Objective: To determine whether vacuum-assisted venous return has clinical advantages over conventional gravity drainage apart from allowing the use of smaller cannulas and shorter tubing.

Methods: A total of 150 valve operations were performed at our institution between February and July 1999 using vacuum-assisted venous return with small venous cannulas connected to short tubing. These were compared with (1) 83 valve operations performed between April 1997 and January 1998 using the initial version of vacuum-assisted venous return, and (2) 124 valve operations performed between January and April of 1997 using conventional gravity drainage. Priming volume, hematocrit value, red blood cell usage, and total blood product usage were compared multivariably. These comparisons were covariate and propensity adjusted for dissimilarities between the groups and confirmed by propensity-matched pairs analysis.

Results: Priming volume was 1.4 ± 0.4 L for small-cannula vacuum-assisted venous return, 1.7 ± 0.4 L for initial vacuum-assisted venous return, and 2.0 ± 0.4 L for gravity drainage ($P < .0001$). Smaller priming resulted in higher hematocrit values both at the beginning of cardiopulmonary bypass ($27\% \pm 5\%$ compared with $26\% \pm 4\%$ and $25\% \pm 4\%$, respectively, $P < .0001$) and at the end ($30\% \pm 4\%$ compared with $28\% \pm 4\%$ and $27\% \pm 4\%$, respectively, $P < .0001$). Red cell transfusions were used in 17% of the patients having small-cannula vacuum-assisted venous return, 27% of the initial patients having vacuum-assisted venous return, and 37% of the patients having gravity drainage ($P = .001$); total blood product usage was 19%, 27%, and 39%, respectively ($P = .002$). Although ministernotomy also was associated with reduced blood product usage ($P < .004$), propensity matching on type of sternotomy confirmed the association of vacuum-assisted venous return with lowered blood product usage.

Conclusions: Vacuum-assisted venous return results in (1) higher hematocrit values during cardiopulmonary bypass and (2) decreased red cell and total blood product usage.

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In April of 1997, vacuum-assisted venous return (VAVR) was introduced as a technical improvement to facilitate use of smaller venous cannulas. With the emergence of minimally invasive surgery, smaller cannulas became necessary to reduce interference with exposure in small incisions. As the advantages of VAVR became evident, its application was broadened to include all cardiac surgery requiring cardiopulmonary bypass (CPB).

Because VAVR was introduced as a technical modification of conventional CPB, no randomized protocol was used. To assess the possible clinical benefit accompanying this technical benefit of surgical flexibility, we compared blood product usage in patients undergoing cardiac surgery with short-tubing VAVR, conventional-tubing VAVR, and conventional gravity drainage.

TABLE 1. Patient and procedure variables (categorical)

Variable	VAVR						P*
	Gravity group (n = 124)		Group 1 (n = 83)		Group 2 (n = 150)		
	n	%	n	%	n	%	
Male	89	72	51	61	103	67	.3
Previous cardiac surgery	22	18	14	17	7	5	.001
Incision							.001
Full sternotomy	58	47	18	22	44	29	
Ministernotomy	45	36	64	77	105	70	
Thoracotomy	21	17	1	1	0	0	
Aortic valve							
Replacement	47	38	24	29	40	27	.1
Repair	8	6	3	4	5	3	.4
Mitral valve							
Replacement	20	16	15	18	12	8	.04
Repair	39	31	39	47	80	53	.001
Combined aortic and mitral procedures	1	1	0	0	11	7	
Surgeon†							
D.M.C.	72	58	83	100	101	67	.001

VAVR, Vacuum-assisted venous return.

*Obtained from χ^2 test.

†Remaining operations are spread among 10 other surgeons.

Patients and Methods

Patients

A new system for VAVR, using a sealed hard-shell venous reservoir (HSR-4000 gold, Baxter Healthcare, Irvine, Calif) connected to a vacuum regulator, was introduced at The Cleveland Clinic Foundation in 1997. With this system, reservoir pressure can be set at -40 to -60 cm H_2O and adjusted as necessary.

This study was designed to assess the group of patients undergoing valve surgery for whom VAVR modified to minimize tubing volume was used and to compare it with a group in which conventional tubing VAVR was used and another group in which conventional gravity drainage was used. Composition of the 3 study groups is described below.

VAVR group 1. This group consisted of 83 patients undergoing valve operations between April 1997 and January 1998 by one surgeon (D.M.C.). This is the initial group in which VAVR with small venous cannulas and conventional length venous tubing was used. Priming volume was reduced by draining the venous lines.

VAVR group 2. This group consisted of 150 patients undergoing valve operations between February and July of 1999. This is the group in which VAVR with important reduction of tubing length was used. A total of 20.4 feet of tubing was removed from the bypass circuit.

Gravity return group. This group consisted of 124 patients undergoing valve operations between January and April of 1997. This is the group in which conventional gravity drainage was used.

Patients undergoing emergency operations, receiving preoperative hemodialysis or port-access procedures, or having operations involving repair or replacement of an aortic aneurysm were excluded. Patient and procedure characteristics of the 3 study groups are compared in Tables 1 and 2.

Data collection and manipulation

Funding was provided by Baxter Healthcare (Irvine, Calif) to support medical record review and data collection; however, the firm did not participate in data analysis or manuscript preparation.

Patient history and preoperative, intraoperative, intensive care unit (ICU), and postoperative data were assembled from medical records. Use of the data assembled in routine patient care was approved by The Cleveland Clinic Foundation's Institutional Review Board. Hematocrit data were extracted from the medical records at 4 time points: preoperatively, shortly after CPB was initiated (first bypass), at aortic clamp removal (first postclamp), and at admission to the intensive care unit (first ICU). The following formulas were used to predict patient blood volume and red blood cell volume, using sex, height (m), weight (kg), and hematocrit value (%):¹

$$\text{Men: Blood volume (L)} = 0.3669 \cdot \text{height}^3 + 0.03219 \cdot \text{weight} + 0.6041$$

$$\text{Women: Blood volume (L)} = 0.3561 \cdot \text{height}^3 + 0.03308 \cdot \text{weight} + 0.1833$$

$$\text{Either: Red cell volume (L)} = \text{blood volume} \cdot \text{hematocrit}/100.$$

The first red cell volume (RCV) on CPB and the first RCV in the ICU were adjusted for priming volume as follows:

$$\text{RCV} = (\text{Priming volume} + \text{blood volume}) \cdot \text{hematocrit}/100.$$

Data Analysis

End Points

End points for the study were (1) total units of packed red blood cells and (2) total units of banked blood products administered intraoperatively and postoperatively. The general policy for transfusion of packed red blood cells was a hematocrit value of 21% or

TABLE 2. Patient and procedure variables (continuously distributed)

Variable	Gravity group (n = 124) Mean ± SD	VAVR		P*
		Group 1 (n = 83) Mean ± SD	Group 2 (n = 150) Mean ± SD	
Demographics				
Age (y)	57 ± 14	58 ± 14	58 ± 14	.8
Body surface area (m ²)	2 ± 0.3	2 ± 0.2	2 ± 0.2	.4
Preoperative hematocrit value (%)	36 ± 5	37 ± 4	36 ± 5	.8
Blood volume (L)	5 ± 1	5 ± 0.9	5 ± 0.9	.2
Red cell volume (L)	2 ± 0.5	1.8 ± 0.4	1.8 ± 0.5	.5
Operative				
Priming volume (L)	2.0 ± 0.4	1.7 ± 0.4	1.4 ± 0.4	<.0001
Hematocrit value (%): first bypass	25 ± 4	26.3 ± 4	27 ± 4.8	.0002
Red cell volume (L): first bypass	1.8 ± 0.5	1.7 ± 0.4	1.7 ± 0.5	.5
Hematocrit (%): first postclamp	27 ± 4	28 ± 8.8	30 ± 4	<.0001
Red cell volume (L): first postclamp	2 ± 0.5	1.8 ± 0.4	1.9 ± 0.5	.2
Bypass time (min)	90 ± 37	70 ± 20	74 ± 24	<.0001
ICU				
Hematocrit value (%): first ICU	32 ± 4	32 ± 4	32 ± 4	.9
Red cell volume (L): ICU	1.6 ± 0.5	1.6 ± 0.4	1.6 ± 0.4	.5

ICU, Intensive care unit; SD, standard deviation; VAVR, vacuum-assisted venous return.

*Obtained from Wilcoxon test.

less, consistent with the National Institutes of Health Consensus Conference on Perioperative Red Blood Cell Transfusion.² This policy was consistent across all 3 groups.

Analytic Strategy

The null hypothesis tested was that there was no difference in packed red cell or total blood product usage (packed red cells, fresh frozen plasma, platelets, or cryoprecipitate) between patients undergoing VAVR and those undergoing conventional gravity drainage. Because the number of units of blood products administered per patient was distributed more "categorically" than continuously, the end points were dichotomized (use or not of blood products) and multivariable logistic regression performed.³ The objective of the analyses was to detect differences in these end points among 3 groups of patients; therefore, a variable representing VAVR group 1 and VAVR group 2 was forced into each model as the initial step. Then, adjusting covariates were sought from patient and procedure variables (Appendix 1) using a guided stepwise approach.⁴ The *P* value criterion used to retain variables in the analyses was .05.

Because the study was not randomized, baseline differences existed among the 3 patient groups (Tables 1 and 2). These differences were quantified by multivariable logistic regression (Appendix Table 1), the results of which were considered in developing propensity models, one for the probability of receiving VAVR 1 and the other VAVR 2.^{5,6} Appendix 2 contains details on the conditional probability computations needed for this, based on methods described by Hosmer and Lemeshow.³ The 2 propensity scores were used to further adjust the multivariable comparisons of groups.

Specific Methods

Logistic regression models were constructed for red blood cell usage and for total blood product usage. Variables considered for

adjustment included demographic and preoperative hematologic measures, cardiac and noncardiac comorbidity, and operative procedures (Appendix 1). Interactions between group and surgical variables were investigated.

Because of confounding between blood product usage and increasing use of minimally invasive incisions across the time frame of the study, the overall results were confirmed in two groups of patients that were pairwise propensity matched for full sternotomy versus minimally invasive approach (Appendix 2).

Results

Influence of VAVR

Compared with gravity drainage, both initial VAVR (group 1), in which venous lines were drained, and VAVR with short tubing (group 2) resulted in incrementally lower priming volume and higher hematocrit values during CPB (Table 2).

Use of Blood Products

Red blood cell transfusions were given to 94 patients, and 99 patients received some form of blood product intraoperatively or postoperatively (Table 3). Packed red blood cells were used in 37% of the gravity drainage group, 27% of VAVR group 1, and 17% of VAVR group 2. After adjusting for age, blood volume, full sternotomy, mitral valve repair, and propensity scores, the probability of receiving red blood cells was 55% lower in VAVR group 1 and 88% lower in VAVR group 2 than in the gravity drainage group (Table 4). The same relations held for total blood product usage (Tables 3 and 5).

Blood products were used more frequently in elderly patients, those with lower blood volume, and those under-

TABLE 3. Outcome variables by group

Variable	Gravity group (n = 124)		VAVR				P *
			Group 1 (n = 83)		Group 2 (n = 150)		
	n	%	n	%	n	%	
Intraoperative RBCs used	31	25	9	11	19	13	.007
Postoperative RBCs used	23	18	16	19	16	11	.1
RBCs used intraop or postop	46	37	22	27	26	17	.001
Blood products used intraop or postop	48	39	22	27	29	19	.002

VAVR, Vacuum-assisted venous return; RBCs, red blood cells.

*Obtained from χ^2 test.

TABLE 4. Probability of receiving packed red blood cells intraoperatively or postoperatively (multivariable logistic regression)

Variable	Without propensity adjustment		With propensity adjustment	
	Coefficient $\pm$ SD	P	Coefficient $\pm$ SD	P
Demographics				
Age (y)	0.042 $\pm$ 0.011	.0001	0.039 $\pm$ 0.011	.0005
Blood volume (L)*	−0.97 $\pm$ 0.171	<.0001	−0.96 $\pm$ 0.178	<.0001
Procedure				
Full sternotomy	0.87 $\pm$ 0.316	.006	1.35 $\pm$ 0.439	.002
Mitral valve repair*	−0.90 $\pm$ 0.342	.008	−0.98 $\pm$ 0.351	.005
Group				
VAVR group 1*	−0.58 $\pm$ 0.387	.1	−0.79 $\pm$ 0.427	.06
VAVR group 2*	−1.19 $\pm$ 0.345	.0006	−1.49 $\pm$ 0.395	.0001
Propensity				
Probability VAVR group 1	—	—	0.15 $\pm$ 0.180	.4
Probability VAVR group 2	—	—	0.38 $\pm$ 0.228	.09
Intercept	1.65 $\pm$ 1.09		2.23 $\pm$ 1.147	

SD, Standard deviation; VAVR, vacuum-assisted venous return.

*Negative coefficient indicates decreased probability of packed red blood cell usage.

going full sternotomy. They were used less often in patients having mitral valve repair (Tables 4 and 5).

Confirmation

Among the propensity-matched pairs of patients for full sternotomy versus minimally invasive incisions, the probability of receiving any blood product was no longer associated with either surgical approach or mitral valve repair (Table 6). However, its association with age, blood volume, and, most important, VAVR was entirely consistent with the findings of the main analysis.

Discussion

Principal Findings

VAVR dates to the earliest days of cardiac surgery,^{7,8} but interest has been rekindled by a new enthusiasm for minimally invasive surgery. As expected from both drainage of venous lines and subsequent shortening of all tubing within the cardiopulmonary bypass circuit, VAVR allowed a no-

tably lower priming volume. Lower priming volume resulted in higher on-pump hematocrit values, and this was associated with a reduced number of patients requiring transfusion. Low priming volume has been shown by Jansen and colleagues⁹ to reduce both post-CPB hyperdynamic response and use of banked blood. Low prime circuits have also been linked to shortened intubation and recovery times.^{10,11}

These findings are at odds with the principle of normovolemic hemodilution. However, in 3 separate studies, Höhn,¹² Casati,¹³ Weiskopf,¹⁴ and their colleagues found a lack of efficacy of normovolemic hemodilution in reducing transfusion requirements in cardiac surgery.

In addition to reducing priming volume, another hypothesis for the clinical benefit of VAVR is the noticeably drier operative field. This reduces the amount of blood exposed to damaging effects of pump suction and basket suction salvage. It may also reduce the amount scavenged by wall

TABLE 5. Probability of receiving any blood products intraoperatively or postoperatively (multivariable logistic regression)

Variable	Without propensity adjustment		With propensity adjustment	
	Coefficient $\pm$ SD	P	Coefficient $\pm$ SD	P
Demographics				
Age (y)	0.039 $\pm$ 0.0106	.0002	0.036 $\pm$ 0.010	.0007
Blood volume (L)*	−0.86 $\pm$ 0.162	<.0001	−0.86 $\pm$ 0.169	<.0001
Procedure				
Full sternotomy	0.74 $\pm$ 0.305	.02	1.23 $\pm$ 0.422	.004
Mitral valve repair*	−0.90 $\pm$ 0.327	.006	−0.98 $\pm$ 0.351	.005
Group				
VAVR group 1*	−0.65 $\pm$ 0.376	.08	−0.88 $\pm$ 0.416	.03
VAVR group 2*	−1.08 $\pm$ 0.330	.001	−1.40 $\pm$ 0.380	.0002
Propensity				
Probability VAVR group 1	—	—	0.14 $\pm$ 0.173	.4
Probability VAVR group 2	—	—	0.38 $\pm$ 0.218	.08
Intercept	1.44 $\pm$ 1.05		2.02 $\pm$ 1.105	

SD, Standard deviation; VAVR, vacuum-assisted venous return.

*Negative coefficient indicates decreased probability of blood product usage.

TABLE 6. Probability of receiving any blood products intraoperatively or postoperatively in propensity-matched pairs of patients for surgical approach (multivariable logistic regression)

Variable	Without propensity adjustment		With propensity adjustment	
	Coefficient $\pm$ SD	P	Coefficient $\pm$ SD	P
Demographics				
Age (y)	0.056 $\pm$ 0.014	<.001	0.050 $\pm$ 0.016	.002
Blood volume (L)*	−1.12 $\pm$ 0.23	<.001	−1.10 $\pm$ 0.24	<.001
Procedure				
Full sternotomy	0.053 $\pm$ 0.36	.9	0.41 $\pm$ 0.52	.4
Mitral valve repair*	−0.43 $\pm$ 0.48	.4	−0.24 $\pm$ 0.70	.7
Group				
VAVR group 1*	−0.74 $\pm$ 0.49	.13	−0.99 $\pm$ 0.55	.07
VAVR group 2*	−1.16 $\pm$ 0.42	.006	−1.42 $\pm$ 0.49	.004
Propensity				
Probability VAVR group 1	—	—	0.177 $\pm$ 0.21	.4
Probability VAVR group 2	—	—	0.24 $\pm$ 0.28	.4
Probability full sternotomy	—	—	0.20 $\pm$ 0.33	.5

SD, Standard deviation; VAVR, vacuum-assisted venous return.

*Negative coefficient indicates decreased probability of blood product usage.

suction. The clinical benefit of VAVR is likely a combination of all effects. This may explain, in part, why incremental improvement was observed when transitioning from conventional gravity drainage to VAVR, without reduction of tubing length, and then to VAVR in its final iteration.

Reducing the need for transfusion of homologous blood products has been a goal of cardiac surgeons since the early 1980s.¹⁵⁻²¹ Identification of transfusion as a mode of disease transmission and an important morbidity has been a strong motivating factor for blood conservation.^{22,23} Modalities such as intraoperative autologous blood donation and retrograde autologous priming have been used with some success,²⁴⁻²⁶ and autotransfusion of shed mediastinal blood has been widely adopted.²⁷

VAVR

Besides the clinical benefits of fewer transfusions, VAVR also permits the use of small-caliber venous cannulas, and the vacuum eliminates air locks that are common with conventional gravity drainage. This is especially apparent with dissection of the right atrium during reoperation and during emergency cannulation when the atrial purse-string suture is not in place. Nevertheless, LaPietra and colleagues²⁸ have voiced concerns about the potential risk of introducing air emboli into the system. They demonstrated that air intentionally introduced into venous lines allowed some microbubbles (<100 μ m) to pass to the arterial cannula. Increasing vacuum (negative pressure) led to an increase in the number of microbubbles transmitted. How-

ever, number of microbubbles ($\text{counts} \times \text{min}^{-1}$) and microbubble flow ($\mu\text{L} \times \text{min}^{-1}$) were still low, so the clinical importance of their findings is unclear. No clinical complications of VAVR have been identified, but, as a precaution, entrained air should be kept to a minimum.

Limitations

Ideally, new, fully developed technology would be evaluated by randomized trial. However, introduction of technology often is iterative, leading in stages to a reengineered process. This was the case with VAVR.

Thus, the principal limitation of this study is its observational character during 2 sequential phases of VAVR implementation and refinement. However, 4 increasingly sophisticated forms of analysis lead us to believe that VAVR itself, not a confounding factor, was associated with the reduced blood product usage discovered. The first was simple unadjusted univariable analysis, which demonstrated incrementally lower blood usage in the VAVR groups. The second was multivariable analysis, used to assess VAVR effects in the presence of statistically and medically significant covariable adjusters. It supported the univariable result. The third was further multivariable adjustment by 2 propensity scores.²⁹ Propensity score adjustment provides a unified way to adjust for group differences in analysis of outcomes in nonrandomized studies such as this. It cannot, however, correct for unmeasured variables that are not correlated highly with variables measured and accounted for in propensity models, and that may affect the end points considered. This adjustment was not statistically significant, supporting both univariable and multivariable analyses. The final form of analysis was propensity-matched-pairs analysis, which confirmed the finding that VAVR itself led to an important reduction in blood product usage, even though full sternotomy was associated with greater blood use and was more common in the gravity drainage group.

Another limitation is that the groups were sequential, rather than concurrent, because of iterative refinements of the technology. This temporal confounding can never be eliminated by propensity adjustment or matching.

The end points themselves posed analytic challenges with respect to distribution of the number of units of blood product used, requiring dichotomization with attendant loss of information content. They also posed a potential problem of bias, in that there was no strict protocol for transfusion; rather, transfusion was a clinical decision based on a general policy that transfusions were called for if the hematocrit value was 21% or less. Thus, we cannot exclude the possibility that blood conservation received a higher priority in the VAVR groups. Fang and colleagues³⁰ have illustrated the relationship between increased operative mortality and hematocrit value during CPB of less than 14% (or <17% in high-risk patients). Our transfusion trigger of 21% is higher

than the danger limit shown by Fang and colleagues, but consistent with recommended guidelines.²

Conclusions

Revived as a technical improvement to facilitate minimally invasive surgery, VAVR also provides clinical benefits during and after CPB. We found that both intraoperative and postoperative hematocrit values were higher and few patients required blood product transfusion. No clinical disadvantages were identified. Given its technical facility and clinical utility, VAVR should be widely applied in cardiac surgery. At The Cleveland Clinic Foundation and now at many other institutions, it is standard for all patients undergoing cardiac surgery with use of CPB.

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Appendix 1

Variables Available for Analysis

Demographics: Age, sex, and body surface area.

Hematology: Preoperative hematocrit, blood volume, and red blood cell volume.

Cardiac comorbidity: History of abnormal rhythm, history of atrial fibrillation, New York Heart Association functional class, and number of previous cardiac operations.

Noncardiac comorbidity: History of diabetes, history of stroke, and history of renal disease.

Procedure: Incision type (full sternotomy, ministernotomy, or thoracotomy), aortic valve replacement or repair, mitral valve replacement or repair, combined aortic and mitral procedure, and surgeon.

Operative: Length of time on cardiopulmonary bypass, first hematocrit value, and red blood cell mass on cardiopulmonary bypass.

APPENDIX TABLE 1. Probability of group membership (parsimonious models)

Variable	Coefficient $\pm$ SD	P
VAVR group 1 vs gravity drainage group		
One or more previous cardiac operations	1.39 $\pm$ 0.42	.002
Ministernotomy	3.3 $\pm$ 0.46	<.0001
Intercept	-1.92 $\pm$ 0.30	
Goodness of fit	C = .83	
VAVR group 2 vs gravity drainage group		
Ministernotomy	2.9 $\pm$ 0.34	<.0001
Intercept	-0.89 $\pm$ 0.177	
Goodness of fit	C = .79	

SD, Standard deviation; VAVR, vacuum-assisted venous return.

Appendix 2

Development of Propensity Scores

Main analysis. The steps described below were used in constructing the 2 group-related propensity scores used in data analyses.^{5,6,29}

Parsimonious models for data subsets. To ensure mutually exclusive probabilities that would generate probabilities adding to 1.0, the data set was the first subset to include only the gravity drainage and VAVR 1 groups. Logistic regression was used to develop a parsimonious model for the probability of being in VAVR group 1 versus gravity drainage, based on patient and procedure variables (and specifically not on outcome variables). Logistic regression was repeated for the subsets of VAVR group 2 and gravity drainage (Appendix Table 1).

Propensity models for data subsets. Covariables from the parsimonious models were pooled and other covariables added that, although not statistically significant in either model, characterized major groups of variables that could give rise to selection bias. These include (1) age, (2) sex, (3) body surface area, (4) New York Heart Association functional class, (5) preoperative red blood cell volume, and (6) one or more previous cardiac surgeries (ministernotomy, mitral valve replacement, aortic valve replacement, and mitral valve repair). This complete set of covariables was incorporated into nonparsimonious logistic propensity models for the 2 subsets of data.

Calculation of propensity scores. Logit values for each of the 2 models, $z_1(x)$ for VAVR group 1 and $z_2(x)$ for VAVR group 2, were calculated for each patient in the entire data set. The 3 conditional probabilities for treatment groups given the chosen covariates were computed as: $\hat{P}(Y = \text{VAVR group 1} | x) = e^{z_1(x)} / (1 + e^{z_1(x)} + e^{z_2(x)})$, $\hat{P}(Y = \text{VAVR group 2} | x) = e^{z_2(x)} / (1 + e^{z_1(x)} + e^{z_2(x)})$, and $\hat{P}(Y = \text{gravity drainage} | x) = 1 / (1 + e^{z_1(x)} + e^{z_2(x)})$, where $\hat{P}$ is the probability of group membership and e is base of the natural logarithms. These probabilities sum to 1.

Verification of propensity score matching. The entire data set was sorted separately by each of the propensity scores. For each, 5 groups (quintiles) of similarly propensity-ranked patients were examined. Matching within quintiles was checked using χ^2 or t tests as appropriate for patient and procedure covariables. Quintiles were homogeneous with the exception of the first quintile in both cases. Because the patients in quintile one for the probability of being in VAVR group 1 were not the same as the patients in

quintile one for the probability of being in VAVR group 2, no patient was omitted from analyses; rather, the propensity scores themselves were used as a mechanism of adjustment.

Use of propensity scores. Two of the 3 resulting conditional probabilities, $\hat{P}(Y = \text{VAVR group 1x})$ and $\hat{P}(Y = \text{VAVR group 2x})$, were used as covariates in multivariable analyses of outcome.

Confirmation Analysis

Using logistic regression as above, both a parsimonious and a propensity model were developed for full sternotomy versus minimally invasive approach. Patients receiving a full sternot-

omy were older ($P = .06$), more symptomatic ($P = .03$), more likely to have had a stroke ($P = .04$) or renal failure ($P = .04$), and less likely to have undergone mitral valve repair ($P < .001$).

A propensity score was calculated for each patient. By the technique of greedy matching, it was used to match one-to-one 98 of the 120 patients having full sternotomy with 98 of the 176 patients having the minimally invasive approach.³¹ These 196 propensity-matched paired patients were analyzed exactly as the main group was; however, propensity adjustment was with respect not only to group but also to surgical approach.

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