Does the Society of Thoracic Surgeons risk score accurately predict operative mortality for patients with pulmonary hypertension?

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Objective: This study assessed the impact of pulmonary hypertension (PH) on morbidity and mortality after the most common cardiac operations and evaluated the accuracy of the Society of Thoracic Surgeons (STS) risk model for patients with PH.

Methods: At a single center between 1994 and 2010, all adult cardiac operations performed with recorded preoperative mean pulmonary arterial pressure (MPAP) and STS predicted mortality were reviewed. MPAP was defined as normal (<25 mm Hg) or as mild (25-34 mm Hg), moderate (35-44 mm Hg), or severe ($\geq$ 45 mm Hg) PH. Multivariate analysis was performed to elucidate the contribution of PH to morbidity and mortality.

Results: In all, 3343 patient records were reviewed. Coronary artery bypass grafting (CABG) was the most common procedure (67.5%), followed by aortic valve replacement (24.9%) and mitral valve procedures (6.3%). Postoperative complications and mortality increased with increasing MPAP. Multivariable analysis found that both moderate (odds ratio, 7.17; $P < .001$) and severe (odds ratio, 13.73; $P < .001$) PH were significantly associated with increased mortality, even after accounting for STS risk. A subset analysis of isolated CABG cases revealed markedly increased mortality for all categories of PH (mild odds ratio, 1.99; moderate odds ratio, 11.5; severe odds ratio, 38.9; $P < .001$).

Conclusions: Morbidity and mortality were independently associated with PH. Observed mortality was significantly higher than predicted by the STS model for patients with moderate and severe PH, particularly in isolated CABG. Addition of PH to the STS risk model should be considered, or alternative tools should be used to assess risk in these patients. (*J Thorac Cardiovasc Surg* 2013;146:631-7)

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Pulmonary hypertension (PH) is defined as the presence of elevated pulmonary arterial pressure, specifically mean pulmonary arterial pressure (MPAP) greater than 25 mm Hg.¹ In patients with acquired cardiac disease, PH is most often due to elevated left atrial pressure.² Long-standing high left atrial pressure can lead to pulmonary vascular remodeling, as evidenced by elevated pulmonary vascular resistance (PVR) or transpulmonary gradient.² The most effective therapy for PH related to left-sided heart disease is correction of the underlying cardiac pathology, such as aortic

valve replacement (AVR) for aortic stenosis; however, PH has long been recognized as a risk factor for morbidity and mortality for patients undergoing cardiac surgery. A host of perioperative factors, such as protamine, hypoxia, hypercapnia, positive pressure ventilation, and systemic inflammatory response to cardiopulmonary bypass and blood products can exacerbate underlying PH and result in right ventricular failure, with additional morbidity and mortality.³

The Society of Thoracic Surgeons (STS) risk model evolved to guide surgeons and cardiologists by estimating risk of operative mortality on the basis of multiple risk factors, including patient demographic characteristics, comorbidities, procedure, and clinical status. Importantly, pulmonary arterial pressure is not one of these preoperative variables, because it is infrequently measured and is dependent on the "clinical state and volume-loading status of the patient when the measurement is obtained."⁴ By comparison, the EuroSCORE risk model does include PH, defined as pulmonary arterial systolic pressure (PASP) greater than 60 mm Hg.⁵ Moreover, the recently released EuroSCORE II model further stratifies PH into moderate (PASP 31-55 mm Hg) and severe (PASP >55 mm Hg).⁶ Although the use of PASP is attractive because it can be estimated noninvasively by echocardiography, there can be significant differences between

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Abbreviations and Acronyms

AVR	= aortic valve replacement
CABG	= coronary artery bypass grafting
CI	= confidence interval
MPAP	= mean pulmonary arterial pressure
OR	= odds ratio
PASP	= pulmonary arterial systolic pressure
PH	= pulmonary hypertension
PROM	= predicted risk of mortality
PVR	= pulmonary vascular resistance
STS	= Society of Thoracic Surgeons

noninvasive estimates and the criterion standard of invasive measurement.⁷

This study sought to assess the impact of PH in cardiac surgery. We hypothesized that PH is associated with greater morbidity and mortality for patients undergoing cardiac operations and that the STS risk model is not valid for patients with significant PH. We included a subset analysis of patients undergoing isolated coronary artery bypass grafting (CABG), because the literature on PH in this most common cardiac operation is limited. We hypothesized that PH would be an independent risk factor for mortality for patients undergoing CABG as well.

MATERIALS AND METHODS**Patients**

The University of Virginia institutional review board approved this study, including a waiver for individual patient consent.

A total of 11,983 adult cardiac operations were performed at the University of Virginia during the study period of January 1, 1994, to December 3, 2010, and were evaluated for inclusion in this study. Patient records from our institutional STS Adult Cardiac Surgery Database were queried. A total of 5241 case records reported MPAP, and 5241 cases had a calculated STS predicted risk of mortality (PROM). A total of 3343 cases included both MPAP and PROM, and these comprise the study population. All included procedures represent standard surgical approaches, and standard STS variable definitions were used. Patient preoperative risk was assessed by the calculated STS PROM for each patient at the time of the operation. MPAP was the first recorded value after placement of the pulmonary artery catheter before incision.

Outcomes

The primary outcomes of interest included differences between observed and expected mortalities for patients with varying severity of PH, as well as risk-adjusted associations between mortality and morbidity and degree of PH. Secondary outcomes included observed differences in patient morbidity, mortality, and resource use. Operative mortality was defined as all patient deaths occurring during hospitalization as well those within 30 days of the date of surgery regardless of discharge status. A composite outcome of major complications was used as a proxy for major morbidity and included the cumulative incidence of postoperative stroke, perioperative myocardial infarction, renal failure, prolonged mechanical ventilation, and pneumonia. Standard STS definitions for postoperative events and complications were used, including prolonged mechanical ventilation (>24 hours), new-onset atrial fibrillation, and renal failure (increase

in serum creatinine level >2.0 or double the most recent preoperative creatinine level).

Statistical Analysis

All study outcomes and data comparisons were established a priori before data collection. Descriptive, univariate statistics included either Pearson χ^2 test or Fisher's exact test for categorical variables and either independent sample single-factor analysis of variance for parametric data comparisons or the Mann-Whitney *U* test for nonparametric data comparisons. Continuous variables are expressed as either mean $\pm$ SD or median with interquartile range, depending on overall variable distribution.

Multiple logistic regression analysis was used to estimate confounder-adjusted associations between PH category and patient morbidity (major complications) and operative mortality. Models were adjusted for patient risk by inclusion of the STS PROM score as well as operating surgeon and operative year. Confounder-adjusted measures of association are reported as odds ratios (ORs) with 95% confidence interval (CI). Model performance and the ability of the model to discriminate between dependent outcomes (major complications and mortality) were assessed with the area under the receiver operating characteristic curve. Predictive Analytics SoftWare (PASW version 18.0.0; IBM Corporation, Armonk, NY) was used for all data manipulation and statistical analyses.

RESULTS**Baseline and Operative Characteristics Stratified by MPAP**

Although ages were similar across groups, the proportion of female patients increased with increasing MPAP (Table 1). Risk factors, including renal failure, lung disease, cerebrovascular disease, and New York Heart Association class IV heart failure, were all more common with increasing severity of PH ($P < .001$ for all). Left ventricular ejection fraction decreased with increasing MPAP ($P < .001$). Interestingly, the incidence of acute myocardial infarction did not vary with MPAP, and the incidences of angina, left main disease, and multivessel disease decreased with increasing MPAP.

Operative characteristics also varied considerably with increasing MPAP. Patients with normal or mildly elevated MPAP were more likely to undergo CABG, whereas patients with moderate or severe PH were more likely to undergo valve operations. Reoperations were more common with increasing MPAP. Accounting for these variations in risk factors and operations, the STS PROM increased with increasing MPAP (normal, 1.8%; mild, 2.3%; moderate, 4.6%; severe, 5.2%; $P < .001$). Finally, crossclamp and CPB times were significantly longer in patients with increasing MPAP.

Adjusted and Unadjusted Risks Rise With Increasing MPAP

Complications occurred more frequently with increasing MPAP (Table 2). Pneumonia, prolonged mechanical ventilation, and renal failure were all significantly associated with PH, as were rare but catastrophic complications such as cardiac arrest. The composite incidence of major complications increased significantly with higher MPAP (normal,

TABLE 1. Patient risk factors and operative characteristics stratified by mean pulmonary arterial pressure

	Total	MPAP (mm Hg)				P value
		Normal, <25	Mild, 25-34	Moderate, 35-44	Severe, >44	
N	3343	1816	1068	334	125	
Age (y, mean $\pm$ SD)	65.6 $\pm$ 11.5	65.9 $\pm$ 11.3	65.7 $\pm$ 11.7	66.2 $\pm$ 11.3	64.2 $\pm$ 11.4	.306
Female (no.)	1017 (30.4%)	508 (28%)	327 (30.6%)	131 (39.2%)	51 (40.8%)	<.001
MPAP (median and IQR)		20 (16-22)	28 (26-30)	39 (36-41)	50 (47-56)	<.001
Preoperative comorbidities (no.)						
Renal failure	306 (9.2%)	133 (7.3%)	100 (9.4%)	49 (14.7%)	24 (19.2%)	<.001
Chronic lung disease	321 (9.6%)	127 (7.0%)	127 (11.9%)	43 (12.9%)	24 (19.2%)	<.001
Peripheral arterial disease	511 (15.3%)	237 (13.1%)	186 (17.1%)	73 (21.9%)	18 (14.4%)	<.001
Cerebrovascular disease	556 (16.6%)	268 (14.8%)	203 (19.0%)	55 (16.5%)	30 (24.0%)	.003
Diabetes mellitus	1185 (35.4%)	572 (31.5%)	426 (39.9%)	135 (40.4%)	52 (41.6%)	<.001
Dyslipidemia	2258 (67.5%)	1249 (68.8%)	726 (68.0%)	202 (60.5%)	81 (67.5%)	.025
Family history of CAD	1727 (51.7%)	953 (52.5%)	562 (52.6%)	149 (44.6%)	63 (50.4%)	.055
Hypertension	2609 (78.0%)	1403 (77.3%)	854 (80.0%)	255 (76.3%)	97 (77.6%)	.318
Cardiac disease (no.)						
Acute MI	1068 (32.5%)	577 (31.8%)	363 (34.0%)	107 (32.0%)	39 (31.2%)	.649
Angina	1647 (49.3%)	976 (53.7%)	505 (47.3%)	123 (36.8%)	43 (34.4%)	<.001
NYHA class						<.001
I	359 (10.7%)	197 (10.8%)	115 (10.8%)	36 (10.8%)	11 (8.8%)	
II	508 (15.2%)	321 (17.7%)	147 (13.8%)	32 (9.6%)	8 (6.4%)	
III	740 (22.1%)	372 (20.5%)	258 (24.2%)	77 (23.1%)	33 (26.4%)	
IV	817 (24.4%)	355 (19.5%)	274 (25.7%)	129 (38.6%)	59 (47.2%)	
Atrial fibrillation (no.)	301 (9.0%)	112 (6.2%)	108 (10.1%)	58 (17.4%)	23 (18.4%)	<.001
LVEF (% , median and IQR)		55% (45%-63%)	54% (40%-60%)	45% (30%-60%)	45% (30%-60%)	<.001
Left main disease (no.)	924 (27.6%)	538 (29.6%)	289 (27.1%)	78 (23.4%)	19 (15.2%)	.001
Diseased vessels (no.)						<.001
None	488 (14.6%)	224 (12.3%)	157 (14.7%)	70 (21.0%)	37 (29.6%)	
1	278 (8.3%)	134 (7.4%)	80 (7.5%)	49 (14.7%)	15 (12.0%)	
2	576 (17.2%)	328 (18.1%)	181 (16.9%)	47 (14.1%)	20 (16.0%)	
3	1992 (59.6%)	1129 (62.2%)	646 (60.5%)	164 (49.1%)	53 (42.4%)	
Status (no.)						<.001
Elective	1765 (52.8%)	986 (54.3%)	571 (53.5%)	149 (44.6%)	59 (47.2%)	
Urgent	1469 (43.9%)	785 (43.2%)	463 (43.4%)	163 (48.8%)	58 (46.4%)	
Emergency	102 (3.1%)	42 (2.3%)	34 (3.2%)	19 (5.7%)	7 (5.6%)	
Salvage	5 (0.1%)	2 (0.1%)	0 (0%)	2 (0.6%)	1 (0.8%)	
Procedure (no.)						<.001
CABG	2258 (67.5%)	1367 (75.3%)	705 (66.0%)	149 (44.6%)	37 (29.6%)	
Isolated AVR	833 (24.9%)	374 (20.5%)	278 (26.0%)	125 (37.4%)	56 (44.8%)	
Isolated MVR	209 (6.3%)	60 (3.3%)	69 (6.5%)	52 (15.6%)	28 (22.4%)	
CABG plus valve	43 (1.2%)	15 (0.8%)	16 (1.5%)	8 (2.4%)	4 (3.2%)	
Reoperation (no.)	195 (5.8%)	76 (4.2%)	64 (6.0%)	39 (11.7%)	16 (12.8%)	<.001
Intraoperative blood products (no.)	856 (25.6%)	375 (20.6%)	311 (29.1%)	128 (38.3%)	42 (33.6%)	<.001
Crossclamp time (min, median and IQR)		69 (54-91)	73 (55-94)	79 (62-101)	80 (64-108)	<.001
Cardiopulmonary bypass time (min, median and IQR)		93 (75-118)	99 (78-125)	109 (88-139)	114 (88-149)	<.001
STS predicted mortality (% , median and IQR)		1.8 (0.8-4.1)	2.3 (1.1-5.3)	4.6 (2.3-9.0)	5.2 (2.3-11.5)	<.001

AVR, Aortic valve replacement; CABG, coronary artery bypass grafting; CAD, coronary artery disease; IQR, interquartile range; LVEF, left ventricular ejection fraction; MI, myocardial infarction; MPAP, mean pulmonary arterial pressure; NYHA, New York Heart Association; STS, Society of Thoracic Surgeons; SD, standard deviation.

10.4%; mild, 14.3%; moderate, 29.9%; severe, 32.0%; $P < .001$). As a consequence, hospital stay of patients with at least moderate PH was on average 2 days longer than that of patients without PH.

As expected, the mortality increased significantly in patients with worsening PH (normal, 1.2%; mild, 2.1%; moderate, 7.2%; severe, 12.8%; $P < .001$). Importantly, the observed mortality incrementally increased beyond that

TABLE 2. Postoperative complications and mortality stratified by median pulmonary arterial pressure

	Total	MPAP (mm Hg)				P value
		Normal, <25	Mild, 25-34	Moderate, 35-44	Severe, >44	
N	3343	1816	1068	334	125	
Pneumonia	128 (3.8%)	42 (2.3%)	44 (4.1%)	29 (8.7%)	13 (10.4%)	<.001
Prolonged mechanical ventilation	331 (9.9%)	115 (6.3%)	108 (10.1%)	77 (23.1%)	31 (24.8%)	<.001
Stroke	81 (2.4%)	42 (2.3%)	22 (2.1%)	11 (3.3%)	6 (4.8%)	.191
Renal failure	178 (5.3%)	63 (3.5%)	52 (4.9%)	45 (13.5%)	18 (14.4%)	<.001
Myocardial infarction	12 (0.4%)	7 (0.4%)	3 (0.3%)	1 (0.3%)	1 (0.8%)	.818
Atrial fibrillation	708 (21.2%)	356 (19.6%)	244 (22.8%)	79 (23.7%)	29 (23.2%)	.111
Cardiac arrest	92 (2.8%)	23 (1.3%)	32 (3.0%)	25 (7.5%)	12 (9.6%)	<.001
Reoperation for bleeding or tamponade	89 (2.7%)	43 (2.4%)	22 (2.1%)	16 (4.8%)	8 (6.4%)	.002
Multiple organ system failure	61 (1.8%)	15 (0.8%)	12 (1.1%)	22 (6.6%)	12 (9.6%)	<.001
Major complications	482 (14.4%)	189 (10.4%)	153 (14.3%)	100 (29.9%)	40 (32.0%)	<.001
Any complication	1199 (35.9%)	579 (31.9%)	395 (37.0%)	164 (49.1%)	61 (48.8%)	<.001
Hospital stay (postoperative d, median and IQR)		5 (4-6)	6 (5-7)	7 (5-11)	7 (5-11)	<.001
Observed mortality		21 (1.2%)	22 (2.1%)	24 (7.2%)	16 (12.8%)	<.001

Data are number with percentage except as specified. *IQR*, Interquartile range; *MPAP*, mean pulmonary arterial pressure.

predicted by the STS risk model with increasing severity of PH (Figure 1). Specifically, in patients with severe PH, the actual mortality was 2.46-fold higher than the STS PROM ($P = .04$).

To explore this relationship further, a multivariate analysis was performed to evaluate the impact of severity of PH on mortality (Table 3). Relative to patients with normal MPAP, moderate PH was significantly associated with mortality (OR, 7.17; $P < .001$), even after accounting for covariates such as STS PROM. Furthermore, patients with severe PH had the greatest adjusted risk of mortality (OR, 13.73; $P < .001$). Multivariate analysis was also performed to assess impact of PH on major complications (Table 3). Even mild PH was associated with increased risk of major complications (OR, 1.47), which increased for moderate (OR, 3.76) and severe PH (OR, 4.24; $P < .001$).

Risk in Isolated CABG Increases With MPAP

Because isolated CABG was the most common operation in this cohort, comprising more than 2000 patients, we analyzed the complication rate and mortality in this subset of patients (Table 4). Similar to the evaluation of the entire study cohort, the incidence of postoperative pneumonia, prolonged mechanical ventilation, and renal failure increased with worsening PH. In fact, more than 50% of patients undergoing CABG with moderate or severe PH had at least 1 complication, compared with only 30% for the entire CABG cohort. Mortality increased markedly with increasing MPAP (normal, 0.9%; mild, 1.7%; moderate, 8.1%; severe, 21.6%; $P < .001$) and to a much greater extent than the STS PROM (normal, 1.3%; mild, 1.6%; moderate, 3.8%; severe, 1.7%; $P < .001$). The ratio of observed to expected mortality is

FIGURE 1. Observed and predicted mortalities stratified by mean pulmonary arterial pressure (MPAP) for the entire cohort.

TABLE 3. Multivariate analysis demonstrating significant association between pulmonary hypertension and mortality and major complications

	Mortality		Major complications	
	OR (95% CI)	P value	OR (95% CI)	P value
Entire cohort				
Normal (<25)	1	<.001	1	<.001
Mild (25-34)	1.74 (0.95-3.18)		1.47 (1.16-1.86)	
Moderate (35-44)	7.17 (3.91-6.68)		3.76 (2.82-5.02)	
Severe (>44)	13.7 (6.68-26.8)		4.24 (2.71-6.45)	
Isolated CABG				
Normal (<25)	1	<.001	1	<.001
Mild (25-34)	1.99 (0.88-4.52)		1.74 (1.29-2.35)	
Moderate (35-44)	11.5 (4.97-26.7)		7.19 (4.82-10.7)	
Severe (>44)	38.9 (13.9-109)		9.02 (4.42-18.4)	

Pulmonary hypertension categories are given as mean pulmonary arterial pressures measured in millimeters of mercury. Model discrimination for mortality (areas under the curve): all patients, 0.76; coronary artery bypass grafting only, 0.80. Model discrimination for major complications (areas under the curve): all patients, 0.68; coronary artery bypass grafting only, 0.76. Covariates included mean pulmonary arterial pressure, Society of Thoracic Surgeons predicted risk of mortality, year of operation, and surgeon. CABG, Coronary artery bypass grafting; CI, confidence interval; OR, odds ratio.

thus exceedingly high in patients with moderate and especially severe PH ($P < .001$).

Multivariate analysis was then performed to evaluate the impact of PH on mortality (Table 3). Even after accounting for STS PROM, patients with moderate PH had an 11.5-fold increased risk of death, whereas patients with severe PH had 38.9-fold increased risk of death ($P < .001$). Risk-adjusted analysis of major complications also demonstrated substantially increased risk with increasing severity of PH (mild OR, 1.74; moderate OR, 7.19; severe OR, 9.02; $P < .001$).

DISCUSSION

Accurate assessment of surgical risk is becoming increasingly important as health care reform focuses attention on quality measures. The STS risk model is widely used in

the United States to predict operative risk and to compare surgical outcomes across surgeons and hospitals. Equally important, the STS risk model is used to aid medical decision making and to counsel patients on the potential risks of surgical interventions, particularly in light of recent advances in percutaneous therapies. Here we have demonstrated that patients with PH have greater operative morbidity, including pneumonia, prolonged ventilation, and renal failure. Furthermore, even after accounting for more risk factors, moderate and severe PH were independently associated with mortality. Although the STS risk model is accurate for patients with normal pulmonary arterial pressures, the model significantly underestimates the actual risk for patients with moderate and severe PH.

PH in Cardiac Surgery

PH has long been considered a risk factor for morbidity and mortality in cardiac surgery, although the literature on the topic is inconsistent and reveals many unanswered questions. Most studies have been small, single-center retrospective analyses focusing on a single operation. Studies have used various definitions of PH. Invasive and noninvasive measurements of pulmonary pressures have been used almost interchangeably. There is a surprising paucity of recent literature describing the impact of PH in cardiac surgery, and most studies have focused on valve disease.

Melby and colleagues⁸ recently reported a single-center retrospective analysis of 1080 patients with aortic stenosis undergoing surgical AVR.⁸ PH (defined as PASP ≥ 35) was independently associated with higher operative mortality. Moreover, long-term mortality was increased in patients with PH, particularly if PVR was elevated at the time of surgery (>3 Wood units) or if PASP remained elevated postoperatively. Ben-Dor and colleagues⁹ published a prospective cohort study of 509 patients with aortic stenosis evaluated at their center for transcatheter AVR as part of the Placement of AoRTic TraNscathetER Valve

TABLE 4. Subgroup analysis of complications and mortality in patients undergoing isolated coronary artery bypass grafting stratified by mean pulmonary arterial pressure

	Total	MPAP (mm Hg)				P value
		Normal, <25	Mild, 25-34	Moderate, 35-44	Severe, >44	
N	2258	1367 (60.5%)	705 (31.2%)	149 (6.6%)	37 (1.6%)	
Pneumonia	79 (3.5%)	32 (2.3%)	25 (3.5%)	16 (10.7%)	6 (16.2%)	<.001
Prolonged mechanical ventilation	191 (8.5%)	72 (5.3%)	62 (8.8%)	46 (30.9%)	11 (29.7%)	<.001
Stroke	37 (1.6%)	17 (1.2%)	13 (1.8%)	6 (4.0%)	1 (2.7%)	.071
Renal failure	114 (5.0%)	48 (3.5%)	30 (4.3%)	27 (18.1%)	9 (24.3%)	<.001
Myocardial infarction	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	NA
Any complication	736 (32.6%)	388 (28.4%)	248 (35.2%)	81 (54.4%)	19 (51.4%)	<.001
Major complications	292 (12.9%)	120 (8.8%)	96 (13.6%)	59 (39.6%)	17 (45.9%)	<.001
Observed mortality	44 (1.9%)	12 (0.9%)	12 (1.7%)	12 (8.1%)	8 (21.6%)	<.001
Predicted mortality (% , median and IQR)		1.3 (0.7%-3.3%)	1.6 (0.9%-3.8%)	3.8 (1.6%-7.7%)	1.7 (1.1%-8.2%)	<.001
Observed to expected mortality ratio		0.69	1.06	2.13	12.71	<.001

Data are number with percentage except as specified. IQR, Interquartile range; MPAP, mean pulmonary arterial pressure; NA, not applicable.

(PARTNER) trial. Pulmonary vascular remodeling was common in patients with severe PH, as demonstrated by elevated PVR (>3 Woods units) in 59% and elevated transpulmonary gradient (>12 mm Hg) in 46%. As expected, overall mortality was higher with increasing PASP, although the authors did not stratify outcomes by intervention (AVR, transcatheter AVR, balloon aortic valvuloplasty, or medical management).

Ghoreishi and colleagues¹⁰ studied the impact of PH (defined as PASP ≥ 40) on operative and long-term mortalities following 873 operations for mitral regurgitation. PH was present in 53% of patients and was associated with higher operative and long-term mortalities. Complications were also more common in patients with PH, including renal failure requiring dialysis, sepsis, respiratory complications, and longer hospital stay.

Literature on PH in patients undergoing CABG is limited. One retrospective study of 2149 patients who underwent CABG at 2 centers observed higher mortality and postoperative myocardial infarction in patients with PH before CPB.¹¹ In our study, which included 2258 CABG procedures, we found a stepwise increase in mortality and major complications in patients with increasing severity of PH. We did not observe an increased risk of postoperative myocardial infarction. One of the most striking findings was the observed mortality of 21.6% for patients undergoing CABG with severe PH, much higher than predicted by STS and much greater than the entire cohort. Although the number of patients with severe PH undergoing CABG was small, if this finding holds true, then patients undergoing isolated CABG with severe PH may be at the highest risk. A potential explanation for this differential risk between patients undergoing CABG and those undergoing valvular surgery is the usually rapid reduction in left atrial pressure after correction of valvular pathology, which is less commonly seen after CABG.

Treatment of PH

During the last 2 decades, there has been a rapid growth in the number and availability of agents to treat PH, both acutely and long term. Pulmonary arterial hypertension resulting from congenital heart disease, connective tissue diseases, or idiopathic causes, has been the primary focus of study. Continuous intravenous epoprostenol, a direct pulmonary vasodilator, has been shown to improve exercise tolerance and survival.¹² Bosentan, which acts by blocking the vasoconstriction and smooth muscle proliferation effects of endothelin, also improves exercise tolerance and delays progression of symptoms.¹³ Sildenafil, a phosphodiesterase inhibitor that induces pulmonary vasodilation by increasing cyclic guanosine monophosphate levels, has been shown to increase exercise tolerance.¹⁴ More recent advances have examined the added value of combination therapy, as well as development of agents with improved

side effect profiles and stability, allowing more convenient dosing regimens.

Although the literature supporting the use of these agents in patients with primary pulmonary arterial hypertension is robust, less is known about their use in patients with left-sided heart disease. Sildenafil and bosentan have been used successfully to lower PVR preoperatively for patients with refractory heart failure undergoing cardiac transplantation.¹⁵ Inhaled nitric oxide and epoprostenol, milrinone, and sildenafil are now commonly used in the perioperative management of cardiac surgical patients, although studies describing their use have been small and focused on hemodynamic rather than clinical end points.^{8,16-18} The frequency of long-term residual PH after corrective cardiac surgery and the benefit of PH agents in these patients have not been well characterized.

Our practice in the perioperative management of patients with PH requiring cardiac surgery has evolved through the years. For elective or urgent cases with evidence of PH or right ventricular dysfunction, we favor preoperative right heart catheterization to guide optimization of volume status and potential use of pulmonary vasodilators. Intraoperatively, we frequently use milrinone and inhaled epoprostenol, with epinephrine for right ventricular dysfunction if needed. Postoperatively, we are cautious with fluid resuscitation, slowly wean milrinone, and occasionally transition patients to oral sildenafil.

EuroSCORE Versus STS for Cardiac Surgery

Many models are available to assess operative risk for cardiac surgery, incorporating a variety of patient and operative characteristics. PH is included in the EuroSCORE, Parsonnet, and Tuman models, but not in other commonly employed models, such as STS and Cleveland Clinic calculators.^{4,5,19-21} Nilsson and colleagues²² compared 19 models for predicting operative mortality in 6222 cardiac operations. The logistic EuroSCORE model was the most accurate model in their analysis, followed by the additive EuroSCORE model and the Cleveland Clinic model. Unfortunately, the STS model was not included in that study. Direct comparisons of the STS and EuroSCORE models have yielded mixed results. A second study by Nilsson and colleagues²³ found superior discriminatory power of the additive EuroSCORE model relative to the STS model in a retrospective single-center analysis of isolated CABG operations.²³ Conversely, several recent studies on AVR for aortic stenosis have found the STS model to be highly accurate in high risk cases, while the EuroSCORE model overestimates operative mortality.^{24,25} Unfortunately, EuroSCORE and EuroSCORE II could not be calculated for our cohort, because PASP and patient mobility information were not available in our database. It is possible that EuroSCORE II would be a more accurate tool for patients with moderate and severe PH.

Limitations

There are several limitations to note. This was a single-center, retrospective analysis that included relatively few patients with severe PH (125; 3.8%). Patients without a measured MPAP were obviously not included, which likely introduced some selection bias. MPAP is a dynamic variable that is dependent on volume status, loading conditions, and ischemia. We stratified patients according to the initial MPAP after the pulmonary artery catheter was placed and before incision. General anesthesia and fasting can falsely lower these values. Elevated MPAP may be due to elevated left atrial pressure, elevated PVR, or a combination of both, and this analysis was not able to differentiate those groups, nor do we have data on reversibility of PVR. The time period for this study was more than 15 years, and substantial changes in the perioperative management of patients with PH occurred during these years. Finally, because the purpose of this study was to evaluate the validity of the STS risk model in the setting of PH, we only included procedures with a calculated STS risk score, thus comprising a subset of all cases at our institution in the specified time period.

CONCLUSIONS

PH is a significant risk factor for morbidity and mortality after common cardiac operations, including CABG, valve operations, and CABG and valve operations together. Although the STS risk model performs well in the setting of normal or mildly elevated pulmonary arterial pressures, it severely underestimates the actual risk in patients with moderate or severe PH. Moreover, moderate and severe PH are independently associated with mortality even after adjusting for STS risk. Alternative risk models should be considered in patients with PH to assess risk adequately. In the future, the inclusion of PH to the STS risk model may allow more accurate assessment of actual risk and should be considered.

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