Do postoperative hemodynamic parameters add prognostic value for mortality after surgical aortic valve replacement?

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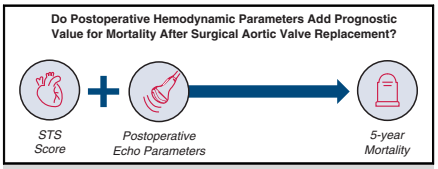
ABSTRACT

Background: Although various hemodynamic parameters to assess prosthetic performance are available, prosthesis–patient mismatch (PPM) is defined exclusively by effective orifice area (EOA) index thresholds. Adjusting for the Society of Thoracic Surgeons predicted risk of mortality (STS PROM), we aimed to explore the added value of postoperative hemodynamic parameters for the prediction of all-cause mortality at 5 years after aortic valve replacement.

Methods: Data were obtained from the Pericardial Surgical Aortic Valve Replacement (PERIGON) Pivotal Trial, a multicenter prospective cohort study examining the performance of the Avalus bioprosthesis. Candidate predictors were assessed at the first follow-up visit; patients who had no echocardiography data, withdrew consent, or died before this visit were excluded. Candidate predictors included peak jet velocity, mean pressure gradient, EOA, predicted and measured EOA index, Doppler velocity index, indexed internal prosthesis orifice area, and categories for PPM. The performance of Cox models was investigated using the c-statistic and net reclassification improvement (NRI), among other tools.

Results: A total of 1118 patients received the study valve, of whom 1022 were eligible for the present analysis. In univariable analysis, STS PROM was the sole significant predictor of all-cause mortality (hazard ratio, 1.40; 95% confidence interval, 1.26-1.55). When extending the STS PROM with single hemodynamic parameters, neither the c-statistics nor the NRIs demonstrated added prognostic value compared to a model with STS PROM alone. Similar findings were observed when multiple hemodynamic parameters were added.

Conclusions: The STS PROM was found to be the main predictor of patient prognosis. The additional prognostic value of postoperative hemodynamic parameters for the prediction of all-cause mortality was limited. (JTCVS Open 2024;17:47-54)



Research question and overview of study design. STS; Society of Thoracic Surgeons.

CENTRAL MESSAGE

Postoperative hemodynamic parameters, including the VARC 3 criteria for prosthesis–patient mismatch, add limited prognostic value to the STS PROM for the prediction of mortality after SAVR.

PERSPECTIVE

Our results do not abate the relevance of prosthetic valve size but rather stress the importance of considering patient characteristics when interpreting hemodynamic parameters for prognostic purposes. Furthermore, these findings challenge the clinical relevance of PPM. Further research on this concept and its relationship with adverse events is warranted.

Prosthesis–patient mismatch (PPM) emerges when a prosthetic heart valve is too small to meet the patient's hemodynamic needs.[1] Several studies using definitions based on categories of effective orifice area (EOA) indexed to body surface area (EOAi)[2,3] have found that this phenomenon of residual hemodynamic obstruction is associated with

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Abbreviations and Acronyms

AS	= aortic stenosis
CABG	= coronary artery bypass grafting
CI	= confidence interval
DVI	= Doppler velocity index
EOA	= effective orifice area
HR	= hazard ratio
LRT	= likelihood ratio test
MPG	= mean pressure gradient
NRI	= net reclassification improvement
PPM	= prosthesis–patient mismatch
SAVR	= surgical aortic valve replacement
STS PROM	= Society of Thoracic Surgeons predicted risk of mortality
SV	= stroke volume
V_{max}	= peak aortic jet velocity
VTI	= velocity-time integral

increased mortality after surgical aortic valve replacement (SAVR).[4-7] In contrast to EOAi, other postoperative hemodynamic parameters to classify PPM have not been considered, and thus their association with mortality remains unclear.

Because hemodynamic parameters as well as mortality are affected by patient characteristics (eg, left ventricular ejection fraction), it is important to adjust for those characteristics when investigating their relationship. The Society of Thoracic Surgeons predicted risk of mortality (STS PROM) is a generally recognized risk score based on comprehensive patient characteristics, and although initially developed to predict 30-day mortality,[8] it also has been proven to predict late mortality after SAVR through up to 10 years of follow-up.[9] Considering the STS PROM as a reference, we evaluated the added prognostic value of postoperative hemodynamic parameters for the prediction of all-cause mortality at 5 years after SAVR.

METHODS

Patient Data

The study population comprised patients enrolled in the Pericardial Surgical Aortic Valve Replacement (PERIGON) Pivotal Trial (ClinicalTrials.gov identifier NCT02088554), a prospective multicenter single-arm trial evaluating the performance of the Avalus bioprosthesis (Medtronic), a stented bovine pericardial aortic valve. The PERIGON study design is described in detail elsewhere.[10,11] In short, the trial included symptomatic patients with moderate or severe aortic stenosis (AS) or chronic severe aortic regurgitation and a clinical indication for SAVR enrolled mainly between 2014 and 2017. All patients received the same stented bioprosthesis. Concomitant procedures were allowed but restricted to coronary artery bypass grafting (CABG) and left atrial appendage ligation, among others. A local Institutional Review Board or Research Ethics Committee provided approval at each site (see Klautz and colleagues[12] for approval numbers and dates), and written informed consent for publication was obtained from all participants. All deaths and valve-related events were adjudicated by an independent clinical events committee (Baim Institute for Clinical Research), and study oversight was kept by an independent data and safety monitoring board (Baim Institute for Clinical Research). Echocardiograms were evaluated by a core laboratory (MedStar Health Research Institute). The mean pressure gradient was calculated using the simplified Bernoulli formula, the EOA using the continuity equation, and the Doppler velocity index (DVI) by dividing the velocity-time integral (VTI) across the left ventricular outflow tract by the VTI across the aortic valve. Forward stroke volume (SV) was determined by multiplying the left ventricular outflow tract cross-sectional area by its VTI.

Study Design

Because echocardiographic assessment during initial hospital stay was considered of limited quality and subject to physiologic postoperative fluctuations related to recovering cardiac function, the hemodynamic parameters for this analysis were obtained from the first follow-up visit after discharge conducted between 3 and 6 months after implant. Patients who underwent previous cardiac surgery (to focus on primary SAVR procedures), who died or withdrew before their first visit, or had no core laboratory assessed echocardiogram available between 3 and 6 months were excluded. Next to STS PROM, several candidate predictors were selected based on previous literature. These comprised five hemodynamic parameters: peak aortic jet velocity (V_{max}), mean pressure gradient (MPG), EOA, EOAi, DVI, and 2 additional derivatives (see Online Data Supplement for calculation): predicted EOAi (pEOAi) and the internal prosthesis orifice area indexed (POAi) to SV. Predicted EOAi has been proposed for determination of the required valve size to avoid PPM in the preoperative setting[13] (eg, constituted in valve charts), and Blackstone and colleagues[14] introduced prosthesis–patient sizing based on geometric dimensions and thus POAi. Categorical predictors for any PPM, moderate PPM, and severe PPM were added to the analysis to enable interpretation of the results considering the current definition of the Valve Academic Research Consortium 3 (VARC 3).[3]

Statistical Analyses

Cox proportional hazards models were used in a nested approach, with time to death as the dependent variable. Death was defined as all-cause mortality. The suitability of predictors was assessed by evaluating missing data (<20%). The scales of EOA, EOAi, DVI, pEOAi, and POAi were reduced by a factor of 10 in all models to create clinically interpretable hazard ratios (HRs) (eg, EOA per 0.1 cm^2 instead of per 1 cm^2). Follow-up started at the first follow-up visit for routine echocardiographic assessment and continued until death or withdrawal from the study, whichever came first. Model performance was investigated using the Nagelkerke R^2, c-statistic, and Brier score. The net reclassification improvement (NRI) and the likelihood ratio test (LRT) were used to study the improvements with the updated models compared to a reference model with STS PROM alone.

The prognostic value of hemodynamic parameters was assessed in steps. In the first step, univariable analyses of all candidate predictors were carried out. In addition, as STS PROM was initially developed to predict 30-day mortality, its 5-year predictive ability was reassessed in a Kaplan-Meier analysis according to quintiles of STS PROM. Survival according to VARC 3 levels of PPM was demonstrated as well. In the second step, the model relating STS PROM to mortality was extended by adding 1 candidate hemodynamic predictor at a time. In the final step, a "full" statistical model was created to explore the maximal predictive performance of postoperative hemodynamic parameters by adding all continuous hemodynamic predictors except parameters with excessive missing values (≥20%) or multicollinearity (Pearson correlation coefficient >0.8); in these cases, the predictor that performed best in terms of the LRT in the previous steps was chosen.

All analyses were carried out using R version 3.6.3 (R Foundation for Statistical Computing; www.r-project.org). A P value <.05 was considered

significant in 2-sided statistical tests. The data underlying this report are owned by the sponsor and will not be shared with third parties for purposes of reproducing the results. More comprehensive information on model building decisions, outcome measures, and our analytical approach is provided in the Online Data Supplement.

RESULTS

Of the 1118 patients who received the study aortic valve, 30 were excluded from our analysis because they died or withdrew consent before their 3- to 6-month echocardiogram, 30 were excluded because no core laboratory–assessed echocardiogram was available between 3 and 6 months postsurgery, and 36 were excluded because they had undergone previous cardiac surgery (Figure E1). Of the excluded patients, 53% had any PPM detected on the discharge echocardiogram. The remaining 1022 patients were included in the current analysis. The patient characteristics and echocardiographic values of all hemodynamic predictors are presented in Table 1. The mean patient age was 70.0 ± 8.9 years, and the mean STS PROM was 1.9 ± 1.3%. Most patients (88%) had a left ventricular ejection fraction of at least 50%. Concomitant procedures are reported in Table E1. Moderate PPM was present in 40% of the patients; severe PPM, in 15%. At the 5-year follow-up, 89 patients had died, and the median duration of follow-up was 1697 days.

The largest percentage of missing values per predictor was 5.6%; therefore, none of the candidate predictors exceeded the exclusion threshold of 20% (Table E2). Multicollinearity was observed for V_{max} and MPG and for EOA and EOAi, with Pearson correlation coefficients of 0.94 and 0.89, respectively (Table E3). The assumptions of proportional hazards and linearity were met for all candidate predictors (Figures E2 and E3).

The results of the univariable analysis of all predictors are summarized in Table 2. STS PROM was a significant predictor of all-cause mortality (HR, 1.40, 95% confidence interval [CI], 1.26-1.55). The HRs of all other predictors were not statistically significant. Moreover, STS PROM performed best in terms of the Nagelkerke R^2 (0.20) and the c-statistic (0.66; 95% CI, 0.60-0.72). Those measures were substantially lower for all other predictors. Nevertheless, the Brier scores were quite similar among all predictors at each time point (Table E4). Survival after the first follow-up visit, stratified by quintiles of STS PROM in Figure 1, was significantly different between the risk groups ($P < .001$, log-rank test). Survival according to VARC 3 levels of PPM was not significantly different ($P = .40$, log-rank test) (Figure 2).

In the updating step, 10 different models were constituted, including STS PROM and 1 hemodynamic predictor per model (Table 3). The effect of STS PROM remained significant in all models, with HRs around 1.40. After adjustment for STS PROM, none of the hemodynamic predictors was associated with all-cause mortality. Correspondingly, the LRTs indicated no significant improvement, and the c-statistics were similar between the models and comparable to the model with STS PROM as the sole predictor variable. Likewise, the NRI did not show improvement for any models.

In the final step, a full statistical model was fitted, including STS PROM and all the continuous hemodynamic predictors. The LRT showed significant improvement, with $P = .003$ (Table E5), whereas this was not supported by the NRI (estimate 0.06; 95% CI, −0.06 to 0.18) or the c-statistic (0.68 [95% CI, 0.63-0.74]) versus 0.66 (95% CI, 0.60-0.72) for STS PROM alone.

Post hoc analyses for dichotomized variants of the predictors MPG (≥20 mm Hg) or DVI (≤0.35) were conducted. In the univariable analysis, the HR for DVI ≤0.35 was 2.23 (95% CI, 1.10-4.53), whereas the c-statistic was comparable to the other models including a single hemodynamic predictor (Table E6). After adjustment for STS PROM, DVI ≤0.35 was a significant predictor of an individual's mortality (HR, 2.75; 95% CI, 1.35-5.63), with a significant P value for the LRT (Table E7). However, the c-statistic of the latter model was similar to that in a model including STS PROM only, and the NRI did not show significant improvement. The dichotomized variant of MPG (≥20 mm Hg) did not provide new insights (Tables E6 and E7).

DISCUSSION

The prognostic value of postoperative hemodynamic parameters for the prediction of all-cause mortality was minimal in addition to the STS PROM, which is available before surgery. The updated models showed limited overall predictive improvement in our data set of more than 1000 SAVR patients at 5 years of follow-up.

The predictive effect of STS PROM on long-term mortality has been demonstrated for different types of cardiac surgeries. Puskas and colleagues[9] found a significant effect of STS PROM after isolated SAVR and after SAVR + CABG. Our findings are in line with their results, with Figure 1 showing reduced survival with increasing STS PROM. Furthermore, STS PROM was the main determinant of model performance in both the extended models and the optimal statistical model.

In contrast, postoperative hemodynamic parameters were of little prognostic value, even for measured or predicted EOAi. Although any PPM according to the current definition[3] was present in the majority of patients (40% with moderate PPM and 15% with severe PPM), there was no association with mortality at 5 years. The EOAi thresholds for classifying PPM were initially based on its relationship with elevated MPG[13]; however, neither parameter added any significant prognostic value.

Our findings conflict to some extent with previous meta-analyses,[4,5] which concluded that (EOAi-based) PPM

TABLE 1. Baseline characteristics and echocardiographic parameters at first follow-up visit after surgical aortic valve replacement (N = 1022)

Variable	Value
Patient characteristics	
Age, y, mean ± SD	70.0 ± 8.9
Male sex, n (%)	767 (75)
Body surface area, m^2, mean ± SD	2.0 ± 0.2
Body mass index, kg/m^2, mean ± SD	29.5 ± 5.5
STS PROM, %, mean ± SD	1.9 ± 1.3
Diabetes mellitus, n (%)	266 (26)
Hypertension, n (%)	766 (75)
Chronic obstructive pulmonary disease, n (%)	120 (12)
Left ventricular ejection fraction >50%, n (%)	898 (88)
Coronary artery disease, n (%)	439 (43)
NYHA class III/IV, n (%)	424 (41)
Previous stroke, n (%)	39 (4)
Peripheral vascular disease, n (%)	70 (7)
Renal dysfunction/insufficiency, n (%)	96 (9)
Operative characteristics	
Valve size implanted, n (%)	
17 mm	1 (0.1)
19 mm	39 (3.8)
21 mm	194 (19)
23 mm	364 (36)
25 mm	320 (31)
27 mm	93 (9.1)
29 mm	11 (1.0)
Echocardiography at first follow-up visit	
Peak aortic jet velocity, ms^{-1}, mean ± SD	2.32 ± 0.4
Mean pressure gradient, mm Hg, mean ± SD	12.0 ± 4.1
Effective orifice area, cm^2, mean ± SD	1.56 ± 0.4
Effective orifice area indexed by BSA, cm^2/m^2, mean ± SD	0.79 ± 0.2
Doppler velocity index, mean ± SD	0.47 ± 0.1
Predicted effective orifice area indexed by BSA, cm^2/m^2, mean ± SD	0.79 ± 0.1
Internal prosthesis orifice area indexed by SV, cm^2/mL, mean ± SD	0.05 ± 0.0
Any prosthesis–patient mismatch, n (%)*	528 (55)
Moderate prosthesis–patient mismatch, n (%)*	384 (40)
Severe prosthesis–patient mismatch, n (%)*	144 (15)

SD, Standard deviation; *STS PROM*, Society of Thoracic Surgeons predicted risk of mortality; *NYHA*, New York Heart Association; *BSA*, body surface area; *SV*, stroke volume. *According to the Valve Academic Research Consortium 3 definition.[3]

negatively impacted survival after SAVR. However, many of the individual studies included in those meta-analyses failed to show a negative association between PPM and survival. A potential explanation can be found in differences in study populations and in methods used to adjust for baseline and procedural characteristics. The STS PROM is a summarized risk score encompassing a broad range of patient characteristics and preoperative information. Other corrections could have been made in the studies included in the meta-analyses.[4,5]

Compared to EOAi, the prognostic value of other postoperative hemodynamic parameters is less evident. In an analysis of the National Echo Database Australia, impaired valvular hemodynamic performance after SAVR, defined based on combinations of V_{max}, MPG, and EOA, was associated with worse survival.[15] However, that study did not define a standardized measurement moment because "only data from the last recorded echocardiographic examination were used," which complicates interpretation. Hahn and colleagues[16] found no significant effect of DVI (whether treated as a continuous or dichotomized variable) on 2-year mortality in the surgical cohorts of the PARTNER 2 and 3 trials. In our analysis, DVI as a continuous parameter was not associated with mortality; however, DVI $\leq$0.35 was found to improve the prediction of time to death for individuals. Nevertheless, this dichotomized variable did not alter the predictive performance of the model in terms of discriminating between patients with and without the outcome (ie, the c-statistic). Hence, these conflicting findings between our analysis and previous literature challenge the clinical relevance of DVI $\leq$0.35, and external validation is necessary. For POAi, Blackstone and colleagues[14] observed no significant effect on intermediate- and long-term mortality in a large study comprising 13,258 patients who underwent SAVR with different valve types, in line with our findings.

The question remains of why the addition of postoperative parameters was of so little value for the prediction of all-cause mortality at 5 years after SAVR. First, as demonstrated above, STS PROM was a very strong predictor of mortality on its own. Second, since hemodynamic parameters depend on both the valve and the patient, and the valvular function is drastically improved by surgery, the patient's contribution prevailed. This contribution consists of such factors as left ventricular function, metabolic requirements, and health status, which are represented to a great extent by the STS PROM. After all, a low postoperative gradient can reflect adequate prosthetic valve size, poor left ventricular function, or both. Third, in our study, residual hemodynamic obstruction after surgery often corresponded to only mild native AS, which is well tolerated. Fourth, the hemodynamic parameter values were concentrated in a narrow range in the postoperative setting. The smaller the between-patient differences, the larger the sample size and number of events required to generate distinctive predictions. Besides, measurement error might disturb predictions even more, as it can induce attenuation as well as amplification of the observed association.[17] As random measurement errors are fixed, the potential consequence is relatively bigger on lower values.

TABLE 2. Univariable relations between candidate predictors and mortality in patients who underwent surgical aortic valve replacement

Variable	HR (95% CI)	R^2	C-statistic (95% CI)
STS PROM	1.40 (1.26-1.55)	0.20	0.66 (0.60-0.72)
V_{max}	1.44 (0.86-2.43)	0.01	0.55 (0.49-0.61)
MPG	1.02 (0.98-1.08)	0.01	0.54 (0.48-0.60)
EOA	1.01 (0.95-1.07)	0.00	0.51 (0.44-0.58)
EOAi	1.62 (0.51-5.18)	0.01	0.53 (0.46-0.59)
DVI	1.07 (0.84-1.34)	0.00	0.52 (0.45-0.59)
pEOAi	1.06 (0.83-1.34)	0.00	0.50 (0.44-0.56)
POAi	1.05 (0.28-3.95)	0.00	0.50 (0.44-0.56)
Any PPM	0.75 (0.49-1.15)	0.01	0.54 (0.49-0.59)
Moderate PPM*	0.70 (0.44-1.13)	0.02	0.55 (0.49-0.60)
Severe PPM*	0.88 (0.48-1.63)		

HR, Hazard ratio; *CI*, confidence interval; *STS PROM*, Society of Thoracic Surgeons predicted risk of mortality; V_{max}, peak aortic jet velocity; *MPG*, mean pressure gradient; *EOA*, effective orifice area; *EOAi*, effective orifice area indexed by body surface area; *DVI*, Doppler velocity index; *pEOAi*; predicted effective orifice area indexed by body surface area; *POAi*, internal prosthesis orifice area indexed by stroke volume; *PPM*, prosthesis–patient mismatch. *The reference category for moderate and severe PPM is no PPM.

These results do not abate the relevance of prosthetic valve size, but rather stress the importance of considering patient characteristics when interpreting hemodynamic parameters for prognostic purposes.

Limitations

Because the current study population comprised mainly low-risk patients, our findings are less generalizable to intermediate- and high-risk AS patients. However, the study

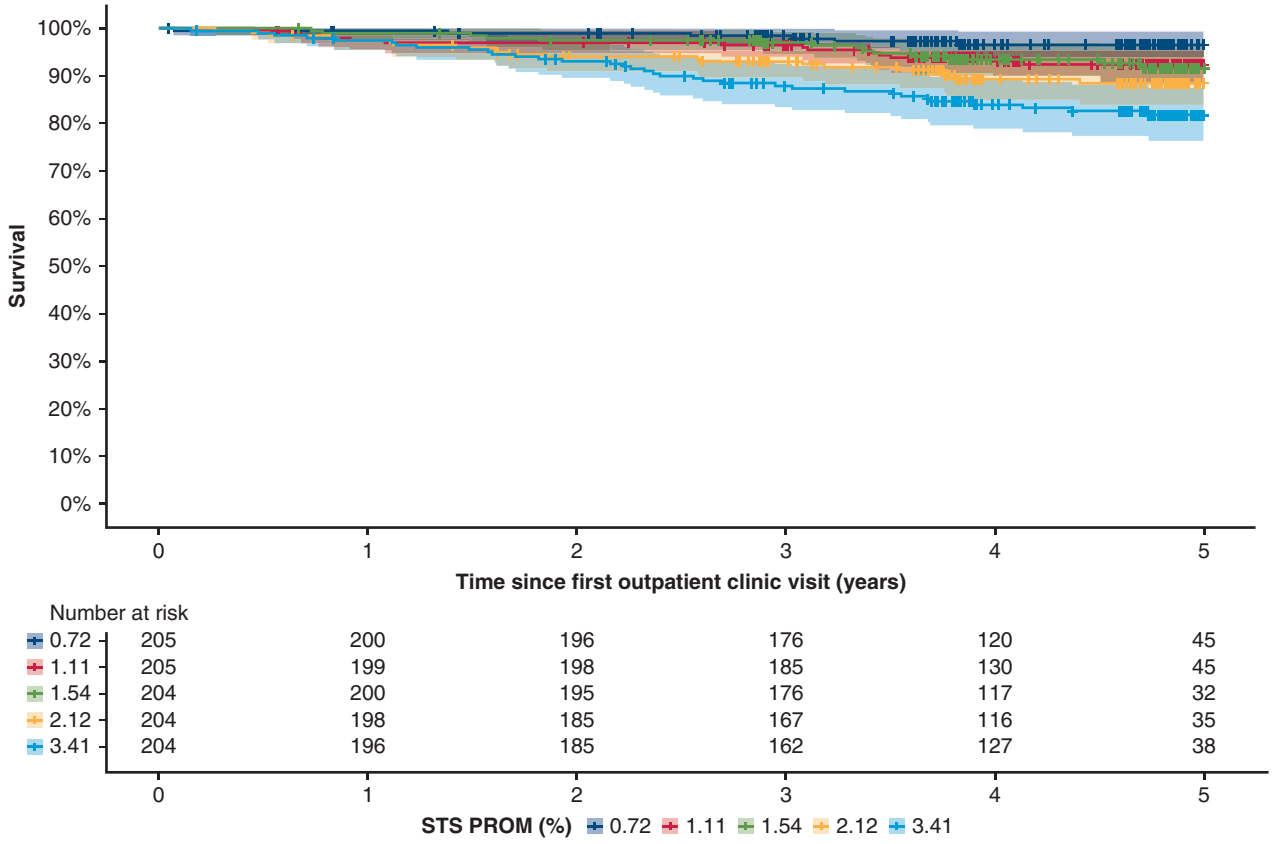

FIGURE 1. Kaplan-Meier survival curves according to quintiles of Society of Thoracic Surgeons predicted risk of mortality (*STS PROM*). The *solid lines* represent the survival curves according to quintiles of STS PROM, including the corresponding 95% confidence intervals. The color legend provides the median STS PROM for each quintile. Censoring is indicated by the "+" sign. Note that the follow-up starts at the first outpatient clinic visit, not at the date of surgery.

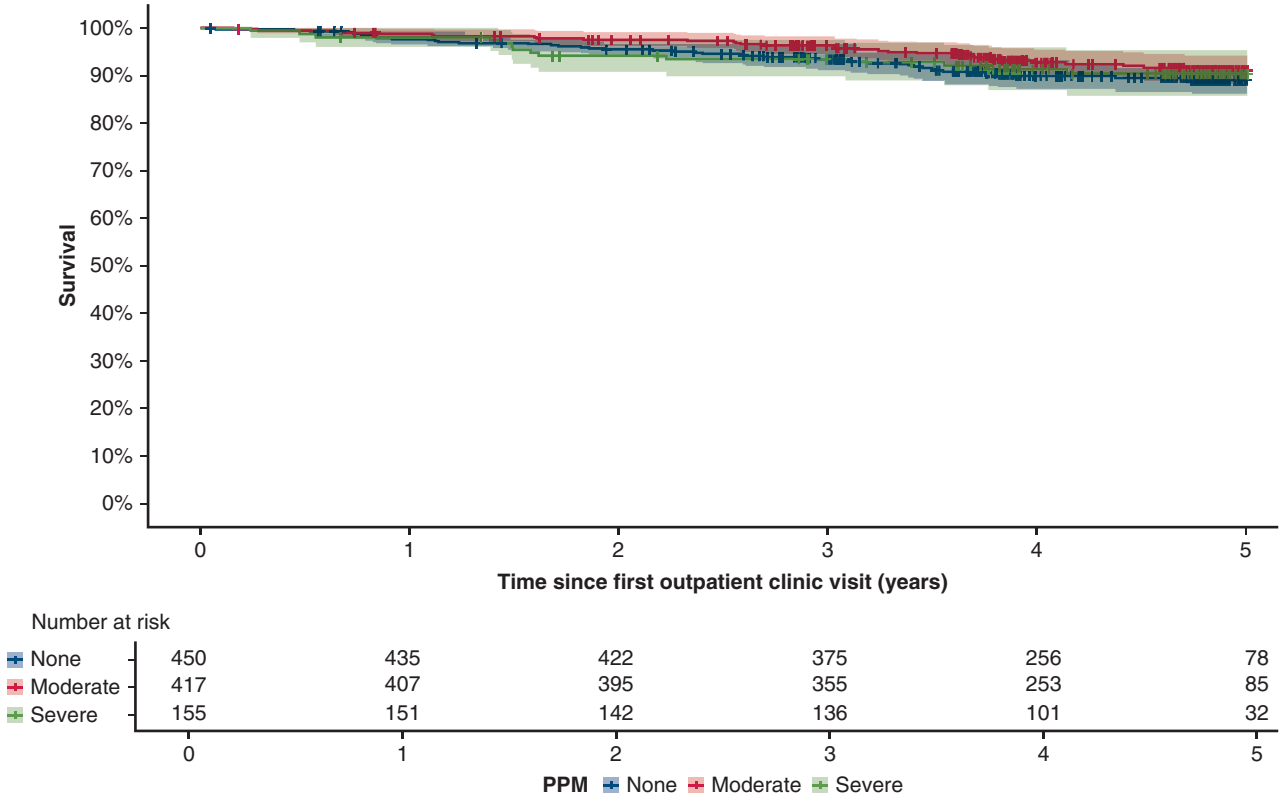

FIGURE 2. Kaplan-Meier survival curves according to Valve Academic Research Consortium 3 levels of prosthesis–patient mismatch (*PPM*). The *solid lines* represent the survival curves according to the levels of PPM, including the corresponding 95% confidence intervals. Censoring is indicated by the "+" sign. Note that the follow-up started at the first outpatient clinic visit, not at the date of surgery.

was executed in an international multicenter setting and allowed some common concomitant procedures such as CABG, boosting the overall representativeness of the population. Moreover, survival in intermediate- and high-risk patients is expected to be even more rigorously affected by patient characteristics such as the STS PROM. In addition, follow-up beyond 5 ears might reveal new associations in this low-risk cohort. Although the number of deaths was largely sufficient to study the added value of single hemodynamic parameters to STS PROM, our main interest—the

TABLE 3. Prognostic value of single hemodynamic predictors in addition to STS PROM for patients who underwent surgical aortic valve replacement

Variable	HR predictor (95% CI)*	HR STS PROM (95% CI)	LRT value†	C-statistic (95% CI)	NRI (95% CI)†
STS PROM +					
V_{max}	1.65 (0.97-2.78)	1.41 (1.28-1.56)	0.062	0.68 (0.62-0.73)	0.00 (−0.08 to 0.08)
MPG	1.03 (0.98-1.08)	1.40 (1.27-1.55)	0.197	0.67 (0.62-0.72)	0.01 (−0.06 to 0.07)
EOA	1.03 (0.97-1.09)	1.41 (1.27-1.56)	0.359	0.67 (0.61-0.72)	0.02 (−0.06 to 0.09)
EOAi	1.03 (0.92-1.16)	1.40 (1.26-1.54)	0.584	0.66 (0.61-0.72)	0.02 (−0.07 to 0.12)
DVI	1.03 (0.81-1.31)	1.40 (1.26-1.55)	0.805	0.66 (0.61-0.72)	0.00 (−0.06 to 0.06)
pEOAi	0.99 (0.78-1.24)	1.40 (1.26-1.55)	0.899	0.66 (0.61-0.72)	0.00 (−0.08 to 0.07)
POAi	1.46 (0.39-5.51)	1.40 (1.27-1.55)	0.899	0.65 (0.59-0.71)	0.01 (−0.08 to 0.09)
Any PPM	0.78 (0.50-1.20)	1.40 (1.26-1.54)	0.221	0.67 (0.61-0.73)	0.03 (−0.07 to 0.13)
Moderate PPM‡	0.73 (0.44-1.18)	1.40 (1.26-1.54)	0.356	0.67 (0.61-0.73)	0.05 (−0.05 to 0.14)
Severe PPM‡	0.91 (0.50-1.68)				

HR, Hazard ratio; *CI*, confidence interval; *STS PROM*, Society of Thoracic Surgeons predicted risk of mortality; *LRT*, likelihood ratio test; *NRI*, net reclassification improvement; V_{max}, peak aortic jet velocity; *MPG*, mean pressure gradient; *EOA*, effective orifice area; *EOAi*, effective orifice area indexed by body surface area; *DVI*, Doppler velocity index; *pEOAi*, predicted effective orifice area indexed by body surface area; *POAi*, internal prosthesis orifice area indexed by stroke volume; *PPM*, prosthesis–patient mismatch. *HR predictor refers to the HR for the predictor specified in each row which is derived from a multivariable model including this predictor and STS PROM. †The LRT and NRI compared a new model with STS PROM plus 1 candidate predictor to a reference model of STS PROM alone. ‡The reference category for moderate and severe PPM is no PPM.

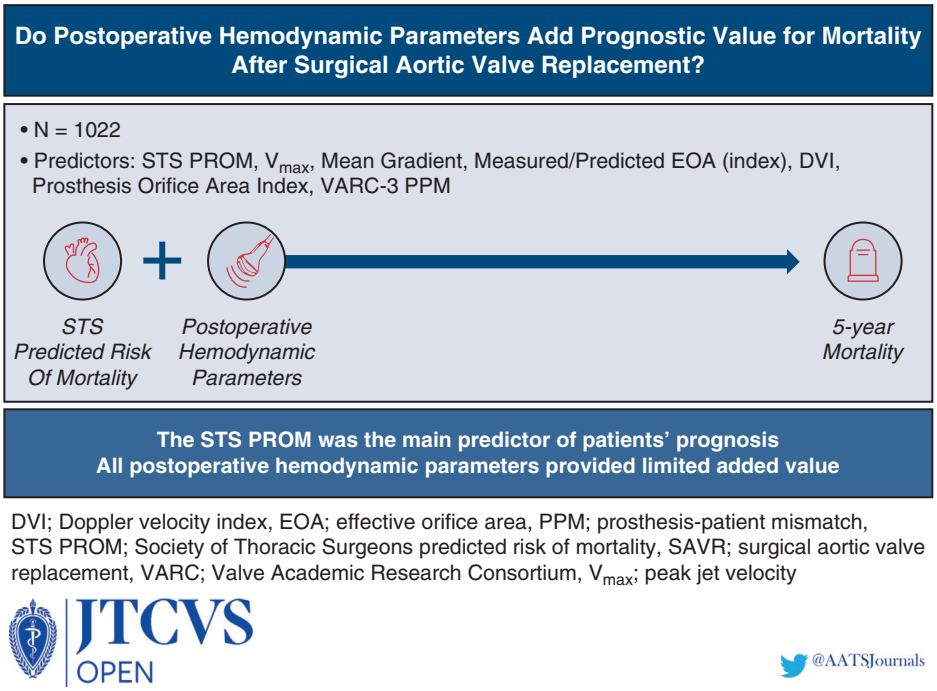

FIGURE 3. Graphical abstract "Do Postoperative Hemodynamic Parameters Add Prognostic Value for Mortality after Surgical Aortic Valve Replacement?"

results from the "full" statistical model—were more prone to overfitting and likely to be affected by collinearity as well. Hence, these results should be interpreted with caution, and external validation in larger cohorts with more events is required to test their robustness. Note that the current analysis addresses only the added value of multiple hemodynamic parameters for predicting mortality after SAVR and thus does not provide any information on the etiologic question of the best operative strategy to optimize hemodynamic performance or clinical outcomes for the patient. Furthermore, cardiovascular mortality would be a highly interesting secondary outcome; however, there were few cardiovascular mortality events in our data, and this would have required the consideration of the competing risk of non-cardiovascular mortality, which further complicates the analysis.

An important strength of this study is that all patients were treated with the same stented bioprosthesis, enabling consistent analysis of hemodynamics unaffected by different valve properties. However, this reduces the generalizability of our results to surgical bioprostheses other than Avalus and to other types of valves, such as mechanical, stentless, and transcatheter aortic valves and homografts.

CONCLUSIONS

The STS PROM was found to be the main predictor of patient prognosis through 5 years of follow-up. In this analysis, the added prognostic value of postoperative hemodynamic parameters for the prediction of all-cause mortality was limited (Figure 3). These results warrant further research on the concept of PPM and its relationship with adverse outcomes.

Conflict of Interest Statement

Dr Velders reported institutional research grant and speaker fees paid to his department by Medtronic. Dr Vriesendorp reported institutional research support and reimbursement of travel expenses from Medtronic. Dr Asch reported institutional grants or research contracts from Medtronic, Abbott, Edwards Lifesciences, Boston Scientific, Biotronik, Corcym, and HLT Medical. Dr Dagenais reported serving as a lecturer, consultant, and proctor for Cook Medical; a proctor and lecturer for Medtronic; and a lecturer for Edwards Lifesciences. Dr Lange reported serving as a consultant for Medtronic, being a stockholder in and receiving royalties from Medtronic, and consulting for HighLife Medical. Dr Reardon reported consulting for Medtronic, Abbott Medical, Boston Scientific, Gore Medical, and Transverse Medical, with fees paid to his department. Dr Rao reported consulting for Medtronic, Gore, and Abbott and serving on an advisory board for Medtronic. Dr Sabik was the North American Principal Investigator for the PERIGON Pivotal Trial, Medtronic. Dr Groenwold reported no conflicts of interest. Dr Klautz was European Principal Investigator of the PERIGON Pivotal Trial and reported research support and consultation fees from Medtronic.

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