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ORIGINAL RESEARCH

# Impact of Managing Provider Type on Severe Aortic Stenosis Management and Mortality

Patricia A. Pellikka, MD; Ratnasari Padang, MBBS, PhD; Christopher G. Scott, MS; Shannon M. E. Murphy, MA; Rosalind Fabunmi, PhD; Jeremy J. Thaden, MD

**BACKGROUND:** Many patients with symptomatic severe aortic stenosis do not undergo aortic valve replacement (AVR) despite clinical guidelines. This study analyzed the association of managing provider type with cardiac specialist follow-up, AVR, and mortality for patients with newly diagnosed severe aortic stenosis (sAS).

**METHODS AND RESULTS:** We identified adults with newly diagnosed sAS per echocardiography performed between January 2017 and March 2019 using Optum electronic health record data. We then selected from those meeting all eligibility criteria patients managed by a primary care provider (n=1707 [25%]) or cardiac specialist (n=5039 [75%]). We evaluated the association of managing provider type with cardiac specialist follow-up, AVR, and mortality, as well as the independent association of cardiac specialist follow-up and AVR with mortality, within 1 year of echocardiography detecting sAS. A subgroup analysis was limited to patients with symptomatic sAS. Patient characteristics and comorbidities at baseline were used for covariate-adjusted cause-specific and multivariable Cox proportional hazard models assessing group differences in outcomes by managing provider type. An adjusted Cox proportional hazard model with additional time-dependent covariates for follow-up and AVR was used to assess these practices' association with mortality. Within 1 year of echocardiography detecting sAS, data revealed that primary care provider management was associated with lower rates of cardiac specialist follow-up (hazard ratio [HR], 0.47 [95% CI, 0.43–0.50], $P<0.0001$) and AVR (HR, 0.58 [95% CI, 0.53–0.64], $P<0.0001$) and with higher 1-year mortality (HR, 1.45 [95% CI, 1.26–1.66], $P<0.0001$). Cardiac specialist follow-up and AVR were independently associated with lower mortality (follow-up: HR, 0.55 [95% CI, 0.48–0.63], $P<0.0001$; AVR: HR, 0.70 [95% CI, 0.60–0.83], $P<0.0001$). Results were similar for patients with symptomatic sAS. All analyses were adjusted for baseline patient characteristics and comorbidities.

**CONCLUSIONS:** For patients newly diagnosed with sAS, we observed differences in rates of cardiac specialist follow-up and AVR and risk of mortality between primary care provider- versus cardiologist-managed patients with sAS. In addition, a lower likelihood of receiving follow-up and AVR was independently associated with higher mortality.

**Key Words:** aortic stenosis ■ aortic valve ■ echocardiography ■ TAVR ■ valve disease

Aortic stenosis (AS) is a common form of valve disease that demonstrates increasing prevalence with advancing age.[1] Of adults ≥65 years, the incidence rate of severe AS (sAS) was 4.4% per year.[2,3] Symptoms were present in 68% of patients with sAS,[2] for whom aortic valve replacement (AVR) is generally recommended.[4] When left untreated, only one third of patients with sAS will survive 5 years.[5] Despite the association of untreated sAS with poor long-term survival, prior research indicates that a considerable proportion of patients with sAS do not receive appropriate therapeutic intervention.[6–9] Deficient or delayed care can have severe consequences, including increased rates of hospitalization, worsening heart failure, and

Correspondence to: Patricia A. Pellikka, MD, Department of Cardiovascular Medicine, Mayo Clinic, 200 1st Street SW, Rochester, MN 55905. Email: pellikka.patricia@mayo.edu

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## CLINICAL PERSPECTIVE

### What Is New?

- Using a large data set of patients with newly diagnosed severe aortic stenosis by echocardiography, we found differences in rates of specialist follow-up, aortic valve replacement, and mortality between patients managed by a primary care provider versus a cardiologist.
- Cardiologist management was associated with higher rates of cardiac specialist follow-up and aortic valve replacement, which were independently associated with lower mortality; improved 1-year survival rate was observed among patients with severe aortic stenosis receiving cardiologist-driven care.

### What Are the Clinical Implications?

- These findings underscore the need for education and other interventions targeting clinicians receiving echocardiography reports that could greatly improve compliance with American College of Cardiology/American Heart Association guidelines, potentially increasing rates for cardiac specialist follow-up, aortic valve replacement, and survival for patients with newly diagnosed severe aortic stenosis.

### Nonstandard Abbreviations and Acronyms

| | |
|---|---|
| **ACC** | American College of Cardiology |
| **AHA** | American Heart Association |
| **AVR** | aortic valve replacement |
| **sAS** | severe aortic stenosis |

death.[5,10–12] The reasons for this deficit are not entirely understood, especially because the advent of transcatheter AVR has made AVR more accessible, even for patients who are considered high risk and unsuitable for surgical AVR.[13] Among potentially appropriate candidates for AVR, common reasons for surgery not being performed include patient refusal,[14] misinterpretations of symptom or lesion severity,[15] patient race[16] and sex,[17] perception of excessive surgical risk,[15] and challenges to local accessibility of treatment.[18] The type of provider managing a candidate for AVR may also influence whether a patient undergoes valve intervention. According to current 2020 American College of Cardiology (ACC)/American Heart Association (AHA) guidelines, referral to a cardiac specialist is a critical step in the management pathway for all patients with sAS (Class 1 recommendation, Level of Evidence: C).[4] However, recent studies suggest that certain types of managing providers, such as primary care providers (PCPs), may be less familiar with guidelines regarding referral for cardiac specialist follow-up.[19] We performed a retrospective analysis based on electronic health record (EHR) data to understand how managing provider type might affect the clinical management and survival of patients with newly diagnosed sAS. Distinguishing patients by managing provider type, we evaluated differences in rates of follow-up evaluation by a cardiac specialist, AVR (transcatheter AVR or surgical AVR), and 1-year mortality. We also assessed the independent association of follow-up and AVR with 1-year mortality. We hypothesized that PCPs and cardiac specialists might have different approaches to sAS management that could ultimately affect patient outcomes.

## METHODS

### Data Source

This retrospective study used de-identified, patient-level, EHR data from the Optum EHR database.[20] The Optum EHR database includes standardized and integrated data from more than 50 health care provider organizations in the United States, not limited to data from the Optum health care provider network, and collectively represents more than 2000 hospitals and 7000 outpatient clinics. Optum EHR data capture clinical diagnoses and procedure codes from the ambulatory and inpatient setting and offers select structured data for patient laboratory and radiographic results. Patient data can be tracked across multiple health care providers, allowing for the longitudinal evaluation of clinical outcomes over time. Optum EHR data are payor agnostic and include all payors, including Medicare. Optum has been the data source for several recent studies investigating disparities in AVR rates based on differences in patient sex[17] and race,[16] as well as clinician variability.[21] The data that support the findings of this study are available from the corresponding author upon reasonable request.

As this was a noninterventional, retrospective, observational study that collected de-identified data for patients who met eligibility criteria, informed consent was not required from patients under an institutional review board exemption status. All aspects of this study were conducted in compliance with the Health Insurance Portability and Accountability Act of 1996 regulations and the act's Omnibus Rule of 2013.

### Study Population

This study included adults (≥18 years old) with newly diagnosed sAS per echocardiography performed between January 2017 and March 2019, as determined from Optum EHR data. Defining criteria for sAS were a mean pressure gradient ≥40 mm Hg, aortic valve

area <1.0 $cm^2$, or peak velocity ≥4.0 m/s and a current or prior diagnosis code indicating AS. Symptomatic sAS was defined as a heart failure diagnosis per *International Classification of Diseases, Tenth Revision* (*ICD-10*) code, ≥2 unique symptoms of sAS, or the same symptom of sAS on multiple dates, occurring within 6 months before echocardiography detecting sAS. Symptom categories included chest pain or pressure, dyspnea with exertion, dyspnea without exertion, and presyncope or syncope; these symptoms were identified based on natural language processing of physician notes rather than via *ICD-10* code.

To ensure longitudinal completeness of data, study participants must have been enrolled in an integrated delivery network[22] and had at least 1 outpatient or pharmacy encounter or evidence of death (per Optum EHR data) during the 1-year follow-up period. Study participants must have been managed by a PCP (general practice, primary care, preventive medicine, family medicine, internal medicine, geriatric medicine) or cardiac specialist (cardiology, interventional cardiology, cardiothoracic surgery). These definitions were used to identify both managing and follow-up providers. Patients managed by midlevel providers were not included in the study owing to ambiguity regarding the definition of midlevel providers in the data set.

Exclusion criteria were as follows: prior sAS diagnosis based on echocardiography, *International Classification of Diseases, Ninth Revision (ICD-9)/ICD-10* code indicating any prior valve procedure, death occurring on the same day as the echocardiography detecting sAS, and AVR within 3 days of echocardiography (a possible indication of a prior sAS diagnosis not captured in EHR). Patients were also excluded if there was no evidence of an outpatient/pharmacy encounter or death within 1 year before *and* 1 year after echocardiography. The data in the year before echocardiography were necessary to identify the managing provider and the data in the year after echocardiography were necessary to assess outcomes.

## Identifying the Managing Provider

A cardiac specialist was identified as the managing provider if Optum EHR data indicated an outpatient visit with 1 of the aforementioned cardiac specialist types in the year before echocardiography. A PCP was identified as the managing provider if Optum EHR data indicated an outpatient visit with 1 of the aforementioned PCP provider types, and no cardiac specialist visit, in the year before echocardiography. Managing provider roles were limited to the discharging, admitting, attending, billing, performing, and consulting physician.

## Outcomes

This study evaluated the association of managing provider type with cardiac specialist follow-up, AVR (surgical AVR or transcatheter AVR), and mortality, as well as the independent association of cardiac specialist follow-up and AVR with mortality, within 1 year of echocardiography newly detecting sAS. Study outcomes reflect data collected throughout the 1-year follow-up period, beginning 1 day after echocardiography detecting sAS.

## Statistical Analysis

Patient demographic characteristics, clinical characteristics, and Elixhauser comorbidities at baseline, reported by managing provider type, were used to assess baseline group differences. The Elixhauser comorbidities are a comprehensive set of comorbidity measures associated with substantial increases in mortality and other clinical outcomes and developed for use with administrative data for a wide range of diseases.[23–25] Comparison of baseline group differences in patient demographic characteristics, clinical characteristics, and comorbidities were based on Mann-Whitney *U* tests (continuous characteristics; variance reported with interquartile range) and Fisher's exact tests (binary characteristics). All outcome models were covariate adjusted for age, sex, region, race (White/under represented racial or ethnic groups), payor, and symptomatic status (Table 1) and for 28 comorbidity indicators from the Elixhauser Comorbidity Index[23] (Table 2).

For the outcomes of cardiac specialist follow-up and AVR by managing provider type, a cause-specific hazard model was used for both adjusted cumulative incidence function plotting and measurement of differences in instantaneous risk between the PCP-managed and cardiac specialist-managed groups. For the outcome of mortality by managing provider type, a multivariable Cox proportional hazard model was used for adjusted cumulative hazard plotting and for measurement of group differences. A subgroup analysis was limited to patients with symptomatic sAS.

A multivariable Cox proportional hazard model with additional time-dependent covariates for cardiac specialist follow-up and AVR was used to assess these practices' independent association with mortality and to determine whether they mitigated any observed association between managing provider type and mortality. For all models, the assumption of proportional hazards was assessed using Kaplan–Meier curves, visual inspection of plots of the Schoenfeld residuals over time, and correlations of the residuals with time (Data S1, Figures S1 through S3). None of the plots showed a major violation of the proportional hazards assumption, and the correlations were all within 0 to +/– 0.1.

**Table 1. Baseline Patient Characteristics for Patients With Severe Aortic Stenosis**

| Characteristic | Total | Managed by PCP | Managed by cardiac specialist | *P* value* |
|---|---|---|---|---|
| No. patients | 6746 | 1707 (25.3%) | 5039 (74.7%) | n/a |
| Age in y, median (interquartile range) | 78.0 (70–85) | 79.0 (70–85) | 77.0 (69–84) | <0.0001 |
| Male sex | 3590 (53.2%) | 845 (49.5%) | 2745 (54.5%) | 0.0004 |
| Under represented racial or ethnic groups | 334 (5.0%) | 79 (4.6%) | 255 (5.1%) | 0.5187 |
| Region | | | | |
| Midwest | 3566 (52.9%) | 1121 (65.7%) | 2445 (48.5%) | <0.0001 |
| Northeast | 1177 (17.4%) | 138 (8.1%) | 1039 (20.6%) | <0.0001 |
| South | 1376 (20.4%) | 323 (18.9%) | 1053 (20.9%) | 0.0823 |
| West | 627 (9.3%) | 125 (7.3%) | 502 (10.0%) | 0.0010 |
| Payor | | | | |
| Commercial | 2243 (33.2%) | 519 (30.4%) | 1724 (34.2%) | 0.0039 |
| Medicare | 3960 (58.7%) | 1054 (61.7%) | 2906 (57.7%) | 0.0031 |
| Medicaid | 140 (2.1%) | 27 (1.6%) | 113 (2.2%) | 0.7576 |
| Other | 298 (4.4%) | 75 (4.4%) | 223 (4.4%) | |
| Uninsured | 105 (1.6%) | 32 (1.9%) | 73 (1.4%) | |
| Symptomatic† | 5165 (76.6%) | 1236 (72.4%) | 3929 (78.0%) | <0.0001 |

For risk adjustment, Medicaid, Other, and Uninsured were combined into a single "Other" category. PCP indicates primary care provider.

**P* values for baseline group differences were based on Mann-Whitney *U* test (age) and Fisher's exact tests (binary characteristics).

†Symptomatic severe aortic stenosis was defined as a heart failure diagnosis per *International Classification of Diseases, Tenth Revision* (*ICD-10*) code, ≥2 unique symptoms of severe aortic stenosis (sAS), or the same symptom of sAS on multiple dates, occurring within 6 months before echocardiography detecting sAS. Symptom categories included chest pain or pressure, dyspnea with exertion, dyspnea without exertion, and presyncope or syncope.

For testing the association of managing provider type on each outcome, a *P* value of <0.017 was considered statistically significant after applying a Bonferroni correction for multiple comparisons based on testing 3 outcomes. Further subgroup analyses and adjustment for time-dependent covariates were planned only if the primary analyses were statistically significant; thus *P*<0.017 was also applied to these additional analyses based on the hierarchical testing approach. Missing values for sex (<0.1%), race (3%), and region (2%) were imputed with the mode. Missing values for payor (18%) were imputed with Medicare for age ≥65 and Commercial for age <65. All analyses were conducted using SAS version 9.4.

# RESULTS

## Population

A total of 6746 patients were analyzed in this study, with 1707 (25%) managed by a PCP and 5039 (75%) managed by a cardiac specialist (Figure 1). About half (51%) of cardiologist-managed patients also saw a PCP in the year before sAS detection by echocardiography. Key characteristics of the total study population included a median age of 78.0 (interquartile range 70–85) years, 3590 (53%) male, 6412 (95%) White, and 3566 (53%) of Midwest geography (Table 1). Of the total study population, 5165 (77%) were considered to have symptomatic sAS, with 1236 (24%) of this subpopulation managed by a PCP and 3929 (76%) managed by a cardiac specialist (Table 1). Differences were observed between PCP-managed and cardiac-specialist managed patients for several Elixhauser comorbidities (Table 2). Of 19 comorbidities for which a statistically significant difference was observed, 4 comorbidities (ie, arrhythmias, congestive heart failure [heart failure with reduced or preserved ejection fraction], peripheral vascular disease, pulmonary circulation disorders [pulmonary vessel disease, pulmonary embolism, pulmonary hypertension, and cor pulmonale]) were more prevalent among cardiac specialist-managed patients (Table 2).

## Association of Managing Provider Type With Cardiac Specialist Follow-Up, AVR, and Mortality

PCP management was associated with lower rate of occurrence of cardiac specialist follow-up (hazard ratio [HR], 0.47 [95% CI, 0.43–0.50], *P*<0.0001; Figure 2) within 1 year of sAS detection by echocardiography. Moreover, PCP management was associated with a lower rate of AVR (among those still at risk) (HR, 0.58 [95% CI, 0.53–0.64], *P*<0.0001; Figure 3). Finally, 1-year mortality was higher for PCP-managed patients (HR, 1.45 [95% CI, 1.26–1.66], *P*<0.0001; Figure 4). These associations persisted when analysis was limited to patients with symptomatic sAS (follow-up: HR, 0.46 [95% CI, 0.42–0.50], *P*<0.0001; AVR: HR, 0.57 [95%

**Table 2. Baseline Patient Elixhauser Comorbidities for Patients With Severe Aortic Stenosis**

| Elixhauser comorbidity | Managed by PCP | Managed by cardiac specialist | *P* value* |
|---|---|---|---|
| Elixhauser count of comorbidities†: Median (interquartile range) | 5 (3–8) | 5 (3–8) | 0.3785 |
| Cardiac arrhythmias | 641 (37.6%) | 2436 (48.3%) | <0.0001 |
| Congestive heart failure (heart failure with reduced ejection fraction or preserved ejection fraction) | 527 (30.9%) | 1943 (38.6%) | <0.0001 |
| Hypertension (complicated) | 449 (26.3%) | 1375 (27.3%) | 0.4493 |
| Hypertension (uncomplicated) | 1356 (79.4%) | 3911 (77.6%) | 0.1195 |
| Peripheral vascular disorders | 412 (24.1%) | 1532 (30.4%) | <0.0001 |
| Blood loss anemia | 59 (3.5%) | 139 (2.8%) | 0.1580 |
| Deficiency anemia | 181 (10.6%) | 413 (8.2%) | 0.0030 |
| Coagulopathy | 136 (8.0%) | 416 (8.3%) | 0.7592 |
| Pulmonary circulation disorders | 208 (12.2%) | 828 (16.4%) | <0.0001 |
| Chronic pulmonary disease | 517 (30.3%) | 1239 (24.6%) | <0.0001 |
| Diabetes (complicated) | 427 (25.0%) | 985 (19.5%) | <0.0001 |
| Diabetes (uncomplicated) | 563 (33.0%) | 1500 (29.8%) | 0.0138 |
| Lymphoma | 36 (2.1%) | 76 (1.5%) | 0.1002 |
| Metastatic cancer | 33 (1.9%) | 78 (1.5%) | 0.2727 |
| Solid tumor without metastasis | 212 (12.4%) | 492 (9.8%) | 0.0025 |
| Fluid and electrolyte disorders | 388 (22.7%) | 824 (16.4%) | <0.0001 |
| Hypothyroidism | 380 (22.3%) | 868 (17.2%) | <0.0001 |
| Liver disease | 85 (5.0%) | 240 (4.8%) | 0.7437 |
| Obesity | 441 (25.8%) | 1092 (21.7%) | 0.0004 |
| Paralysis | 21 (1.2%) | 37 (0.7%) | 0.0676 |
| Other neurological disorders | 168 (9.8%) | 313 (6.2%) | <0.0001 |
| Peptic ulcer disease (excluding bleeding) | 37 (2.2%) | 73 (1.4%) | 0.0467 |
| Drug abuse | 32 (1.9%) | 76 (1.5%) | 0.3151 |
| Alcohol abuse | 33 (1.9%) | 109 (2.2%) | 0.6262 |
| Depression | 290 (17.0%) | 584 (11.6%) | <0.0001 |
| Psychoses | 25 (1.5%) | 31 (0.6%) | 0.0017 |
| Renal failure | 483 (28.3%) | 1203 (23.9%) | 0.0003 |
| Rheumatoid arthritis/collagen vascular diseases | 128 (7.5%) | 295 (5.9%) | 0.0178 |
| AIDS/HIV† | 2 (0.1%) | 9 (0.2%) | 0.7407 |
| Abnormal weight loss | 123 (7.2%) | 227 (4.5%) | <0.0001 |

PCP indicates primary care provider.
**P* values for baseline group differences were based on Mann-Whitney *U* test (Elixhauser score) and Fisher's exact tests (individual comorbidities).
†Comorbidity not used for risk adjustment.

CI, 0.51–0.64], *P*<0.0001; mortality: HR, 1.52 [95% CI, 1.32–1.76], *P*<0.0001). All analyses were adjusted for baseline patient characteristics and comorbidities.

## Association of Cardiac Specialist Follow-up and AVR With Mortality

After adjusting for baseline patient characteristics and comorbidities, cardiac specialist follow-up and AVR were independently associated with lower risk of mortality (follow-up: HR, 0.55 [95% CI, 0.48–0.63], *P*<0.0001; AVR: HR, 0.70 [95% CI, 0.60–0.83], *P*<0.0001). After additional adjustment for cardiac specialist follow-up and AVR as time-dependent covariates, management by a PCP was still associated with higher risk of mortality, although to a lesser degree (HR, 1.20 [95% CI, 1.04–1.38], *P*=0.0129).

# DISCUSSION

Among 6746 adults with newly diagnosed sAS, after adjustment for baseline patient characteristics and comorbidities, we found significantly lower rates of cardiac specialist follow-up evaluation and AVR for patients managed by a PCP as compared with a cardiac

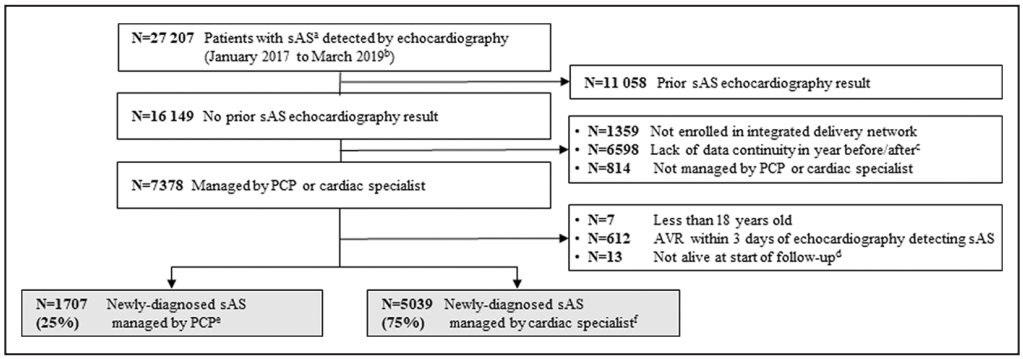


**Figure 1. Consort diagram.**
AVR indicates aortic valve replacement; PCP, primary care provider; and sAS, severe aortic stenosis. [a]Defining criteria for sAS were a mean pressure gradient ≥40 mm Hg, aortic valve area <1.0 $cm^2$, or peak velocity ≥4.0 m/s; and a current or prior diagnosis code indicating aortic stenosis. [b]Patients were included if the date of aortic stenosis diagnosis by *International Classification of Diseases, Tenth Revision* (*ICD-10*) code was at any point on or before the date of echocardiography detecting sAS. [c]Lack of data continuity was defined as no evidence of an outpatient/pharmacy encounter or death within ±1 year of echocardiography detecting sAS. [d]Follow-up period: 1 to 365 days after echocardiography detecting sAS. [e]A PCP was identified as the managing provider if Optum EHR data indicated an outpatient visit with 1 of the study's selected PCP provider types, and no cardiac specialist visit, in the year before echocardiography detecting sAS. [f]A cardiac specialist was identified as the managing provider if Optum EHR data indicated an outpatient visit with 1 of the study's selected cardiac specialist types in the year before echocardiography detecting sAS.

specialist. PCP-managed patients were less likely to undergo AVR even when the analysis was limited to patients with symptomatic sAS, which represents the most severe stage of sAS (Stage D) according to current 2020 ACC/AHA guidelines and for whom AVR is recommended with very few exceptions.[4] PCP-led

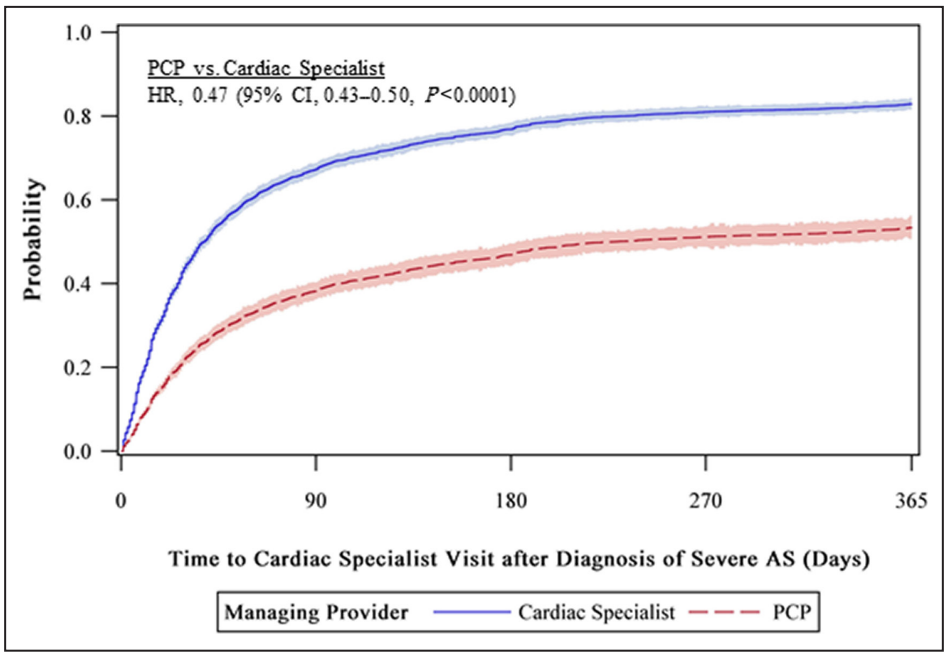


**Figure 2. Association of cardiac specialist follow-up with managing provider type for patients with severe aortic stenosis.**
Plot based on adjusted Cumulative Incidence Function and HR based on cause-specific hazard model. Covariates include age, sex, White race, region, payor, 28 Elixhauser comorbidity indicators, symptomatic indicator, and year of severe aortic stenosis diagnosis. The colored shading around each curve represents the 95% CI. AS indicates aortic stenosis; HR, hazard ratio; and PCP, primary care provider.

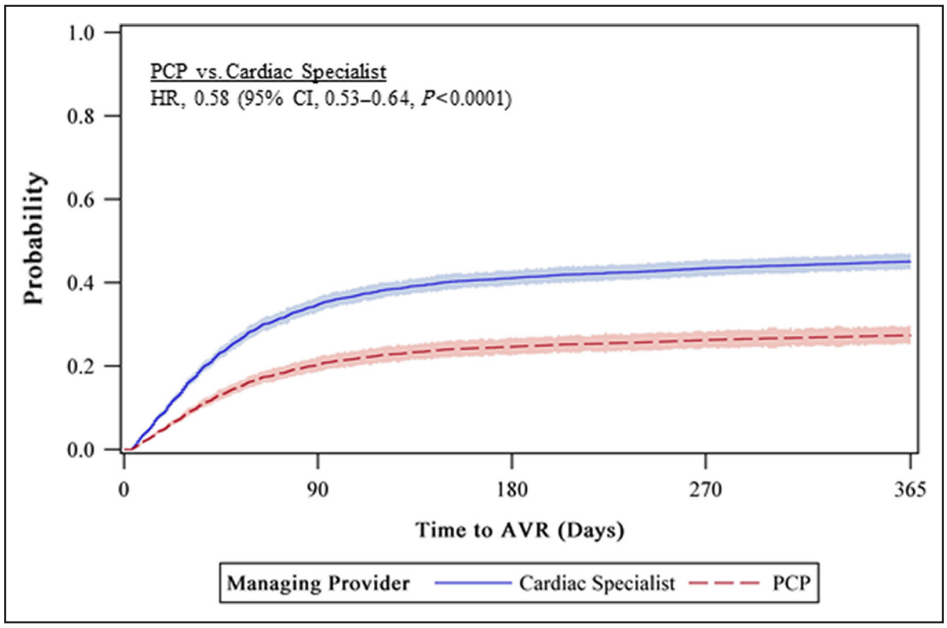


**Figure 3. Association of aortic valve replacement with managing provider type for patients with severe aortic stenosis.**
Plot based on adjusted Cumulative Incidence Function and HR based on cause-specific hazard model. Covariates include age, sex, White race, region, payor, 28 Elixhauser comorbidity indicators, symptomatic indicator, and year of severe aortic stenosis diagnosis. The colored shading around each curve represents the 95% CI. AVR indicates aortic valve replacement; HR, hazard ratio; and PCP, primary care provider.

management of sAS was also associated with higher risk of mortality, regardless of patients' symptom status.

## Cardiac Specialist Follow-Up and Aortic Valve Replacement

Primary care providers play a crucial role in patient care. Their initial clinical evaluation frequently is key to discovering underlying cardiovascular disease and it should be noted that 51% of cardiologist-managed patients also saw a PCP in the year before echocardiogram confirmation of sAS. Meanwhile, follow-up evaluation by a specialist provider represents an opportunity for in-depth assessment of concerning findings by an expert in the field. Specialists usually receive years of additional training regarding identification and best practice management of diseases associated with their practice. A key component of this training is gaining familiarity with clinical management guidelines. According to current 2020 ACC/AHA guidelines, referral to a cardiac specialist is a critical step in the clinical management pathway for all patients with sAS (Class 1 recommendation, Level of Evidence: C).[4] Evaluation by a cardiac specialist provides the best opportunity for accurate assessment of patient disease severity and symptomatology, although variability in the management of patients with sAS among cardiologists has been described.[26] As the guidelines for sAS management are largely based on these findings, accurate characterization of a patient's clinical presentation is key to appropriate management and good outcomes. Visiting with a cardiac specialist may also empower patients to participate in fully informed decision-making regarding their condition, as specialists may have greater experience with issues warranting consideration, such as the natural history of untreated sAS and AVR procedural risks.[26]

Among many benefits, follow-up evaluation by a cardiac specialist can improve determination of valvular lesion severity, which is underestimated in up to 22% of patients with sAS and may warrant treatment with AVR.[27–29] Underestimation of sAS is especially common in patients with low-flow, low-gradient AS because of difficulties in classifying the severity of their disease.[30] This may result in nonreferral for (or delayed performance of) AVR procedures that enhance survival for these patients when compared with medical management alone.[31] Underscoring the importance of follow-up evaluation, our study found cardiac specialist follow-up to be associated with lower risk of 1-year mortality for patients with sAS, with or without adjustment for managing provider type.

There is much discussion in the literature regarding the effect of symptom status on clinical outcomes for patients with sAS.[32,33] Our study found similar results between all patients with sAS and patients with

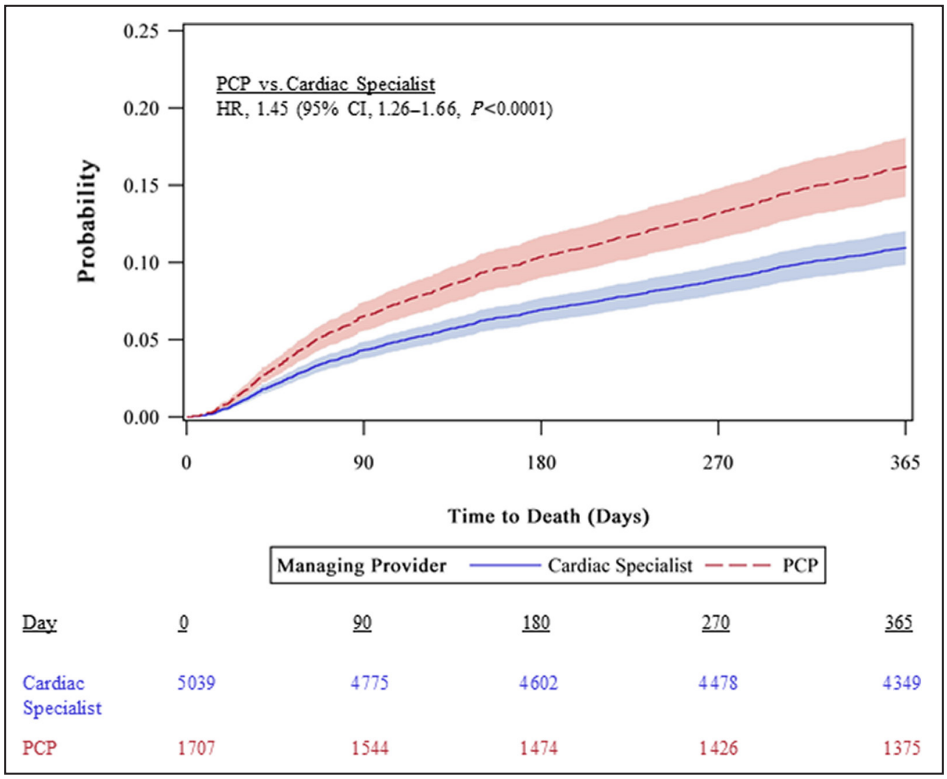


**Figure 4. Association of mortality with managing provider type for patients with severe aortic stenosis.**
Plot based on adjusted cumulative hazard risk and HR from multivariable Cox proportional hazard model. Covariates include age, sex, White race, region, payor, 28 Elixhauser comorbidity indicators, symptomatic indicator, and year of severe aortic stenosis diagnosis. The colored shading around each curve represents the 95% CI. HR indicates hazard ratio; and PCP, primary care provider.

symptomatic sAS, suggesting that even in the presence of symptoms, PCP-managed patients were less likely to be referred for specialist care, were less likely to receive AVR treatment, and were associated with higher risk of mortality. Collaboration across care teams to ensure follow-up with a cardiac specialist, and access to potentially lifesaving AVR, is thus a key component of appropriate clinical management for patients with sAS, regardless of symptomatic status.

Previous studies indicate that rates of referral for cardiac specialist follow-up vary widely for sAS patients with an indication for AVR.[15,34–36] This variability is likely multifactorial. Patients with sAS and symptoms of angina (as opposed to symptoms of heart failure or syncope) and high aortic valve pressure gradient (as opposed to low gradient despite small aortic valve area) have been found to receive referrals more frequently.[35] Higher referral rates have also been found for patients with sAS and ischemic heart disease or prior pacemaker therapy, as well as patients with sAS and evidence of medical futility, suggesting an influence of known cardiovascular disease and patient complexity on the desire for specialty care.[15] Another potential contributor to wide-ranging referral rates may be the presence of certain patient comorbidities. To address this gap in the literature, we collected detailed information (and adjusted) for the presence of 28 cardiovascular and noncardiovascular Elixhauser comorbidities among study participants. We also conducted a subgroup analysis for patients with few (≤3) comorbidities as determined by the Elixhauser score (n=2049 or 30% of the total study population). The results in patients with minimal comorbidities were similar to the total study population (Table S1).

Our study found noncardiovascular and nonpulmonary comorbidities to be more prevalent in the PCP-managed group, raising the possibility that signs or symptoms of these conditions might interfere with detection of sAS (or other cardiac pathology) and, ultimately, cardiac specialist referral. Future work is needed to evaluate whether patients with sAS and certain comorbidities are more likely to have PCP or cardiac specialist managing providers or experience different rates of referral for specialist evaluation. Variability in referral rates thus has many drivers. Aspects of both the patient and provider influence whether appropriate follow-up and treatment occur.

## Mortality

Many studies have evaluated the impact of AVR on the mortality of patients with sAS and symptomatic sAS, with receipt of AVR consistently associated with enhanced survival for patients in whom it is recommended.[37,38] Consistent with prior work, our study found a significant association between AVR and reduced risk of 1-year mortality. Through its novel evaluation of the relationship between managing provider type and mortality, our study also found that cardiac specialist-managed patients with sAS have a 45% lower risk of mortality than their PCP-managed counterparts. Given the different contexts in which they perform patient care, PCPs and cardiac specialists may understandably have variable approaches to sAS management. Part of this variation can be attributed to differential approaches affecting cardiac specialist follow-up and AVR practices, but reasons for the remaining variation have yet to be explained. Indeed, the degree of association between managing provider type and risk of mortality was reduced, although not eliminated, after controlling for cardiac specialist follow-up and AVR (HR, 1.45 before adjustment; HR, 1.20 after adjusting for cardiac specialist follow-up and AVR).

## Adherence to Clinical Guidelines

Several actions have been taken to improve adherence to ACC/AHA guidelines, including a proposal for guideline-based alerts within echocardiography reports indicating sAS[39] and the inclusion of guideline-based statements by interpreting physicians within echocardiography reports noting other cardiac pathology.[40] These efforts have focused on system-, provider-, and patient-level interventions, with varying levels of impact on patient outcomes.[41] This study suggests that educational interventions targeting clinicians receiving echocardiography reports could greatly improve compliance with ACC/AHA guidelines, potentially increasing rates for cardiac specialist follow-up, AVR, and survival for patients with newly diagnosed sAS.

## Study Limitations

Our study has several limitations. First, inherent challenges of using Optum EHR data include the potential incompleteness of patient longitudinal data. We have mitigated this limitation by including only patients enrolled in integrated delivery networks and excluding patients with lack of data continuity (ie, no evidence of an outpatient encounter or death) within ±1 year of echocardiography detecting sAS.

A second potential study limitation is overestimation of the cardiac specialist follow-up rate for cardiac specialist-managed patients if they returned to their managing provider for follow-up evaluation. This limitation would not apply to the follow-up rate for PCP-managed patients. Similarly, the data set did not include data on referrals, so we used completed visits as a proxy for referrals. However, there are many known challenges that affect the specialty-referral process in the United States, which should be examined in future studies.[42] Third, we relied on *ICD* codes to define the comorbidities used for adjustment, including heart failure used to identify symptom status, which may have underestimated the true prevalence of these conditions in our study population.[43] Fourth, our results are representative of patients who received care at all sites participating in the Optum EHR offering, which may not be generalizable nationwide or to dissimilar patient populations. However, the Optum EHR database supports a large provider network that is not restricted to the Optum Care Network; it is electronic medical record and payor agnostic. Finally, there are important variables that are unavailable in this data set, which have the potential for residual confounding. For example, we were able to adjust our analysis for patient regions, but the data set did not allow for adjustment based on other socioeconomic barriers to referral, such as rural settings and ability to take time off work. It will be important to confirm these results in other data sets that can provide additional patient information.

# CONCLUSIONS

In studying a nationwide, US-based cohort of patients with newly diagnosed sAS, we found significant variability in rates of sAS management practices and risk of mortality based on managing provider type. Patients managed entirely by PCPs, as compared with cardiac specialists, were less likely to receive follow-up evaluation by a cardiac specialist and AVR (key components of ACC/AHA guidelines for sAS management) and demonstrated higher mortality at the end of the 1-year follow-up period. Considering the independent association found for both cardiac specialist follow-up and AVR with reduced risk of 1-year mortality, this study highlights the critical importance of appropriate follow-up care in achieving optimal clinical outcomes for patients with sAS. Our findings underscore the importance of a collaborative approach to sAS patients, including partnership between PCPs and cardiac specialists to optimize patient care and evaluation, as well as initiatives to align clinical practices more closely with ACC/AHA management guidelines. Further studies are warranted to examine if these results are generalizable to other populations.

## ARTICLE INFORMATION

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## Affiliations

Department of Cardiovascular Medicine (P.A.P., R.P., J.J.T.) and Department of Quantitative Health Sciences (C.G.S.), Mayo Clinic, Rochester, MN; and Edwards Lifesciences, Irvine, CA (S.M.M., R.F.).

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## Supplemental Material

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# SUPPLEMENTAL MATERIAL

**Data S1. Supplemental Methods**

*Proportional Hazard Assumption Testing*

We conducted proportional hazards assumption testing using: 1) Kaplan-Meier curves, 2) visual inspection of plots of the Schoenfeld residuals over time, and 3) correlations of the residuals with time (Figures S1-S3). The 2nd and 3rd tests were conducted based on the Mayo Clinic's SCHOEN Macro for SAS.[44] None of the plots showed a major violation of the proportional hazards assumption, and the correlations were all within 0 to +/- 0.1.

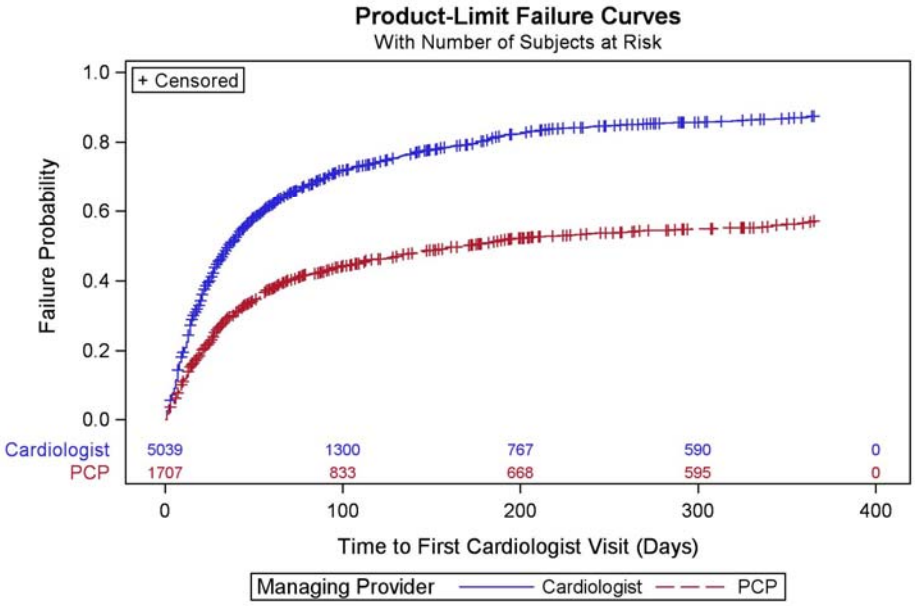
**Table S1. Subgroup analysis for patients with few comorbidities.**

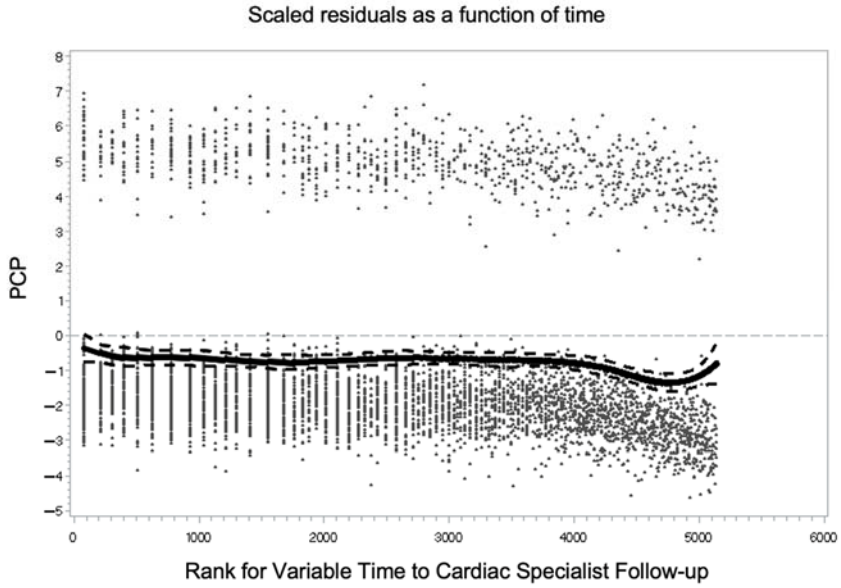
| | Total Study Population (n=6,746) | Subset with Few Comorbidities* (n=2,049, 30% of Total) |
|---|---|---|
| Cardiac Specialist Follow-up | OR=0.47, 95% CI (0.43, 0.50), p<0.0001 | OR=0.44, 95% CI (0.39, 0.51), p<0.0001 |
| AVR | OR=0.58, 95% CI (0.53, 0.64), p<0.0001 | OR=0.44, 95% CI (0.37, 0.53), p<0.0001 |
| Mortality | OR=1.45, 95% CI (1.26, 1.66), p<0.0001 | OR=1.53, 95% CI (1.09, 2.16), p=0.0141 |

* Based on an Elixhauser Score <=3, which was selected to capture the bottom quartile. Subgroup includes 509 (25%) managed by a PCP and 1540 (75%) managed by a cardiac specialist.

Abbreviations: AVR, aortic valve replacement; CI, confidence interval; OR, odds ratio; PCP, primary care provider

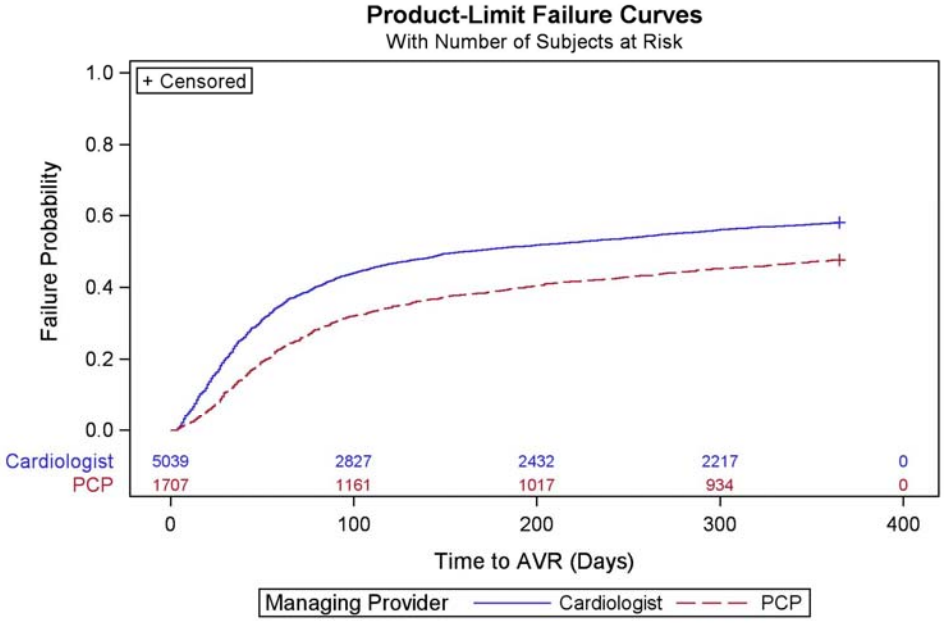
**Figure S1. Kaplan-Meier and Schoenfeld residual plots for cardiac specialist follow-up.**

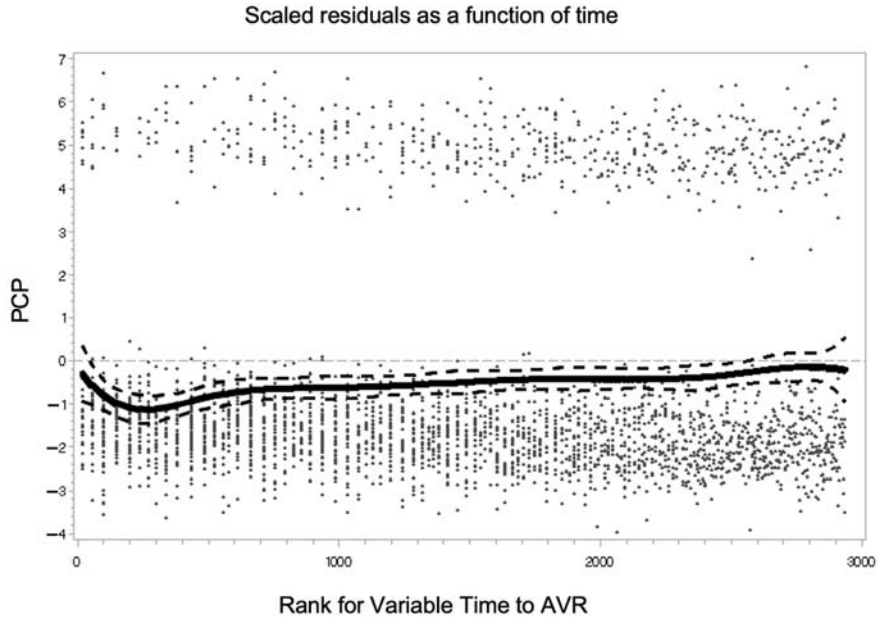



Schoen Macro Correlation of Covariates with Time to First Cardiac Specialist Visit:
All correlations within =/-0.1
Managing Provider Correlation= -0.06060, $p<0.0001$

**Figure S2. Kaplan-Meier and Schoenfeld residual plots for aortic valve replacement (AVR).**



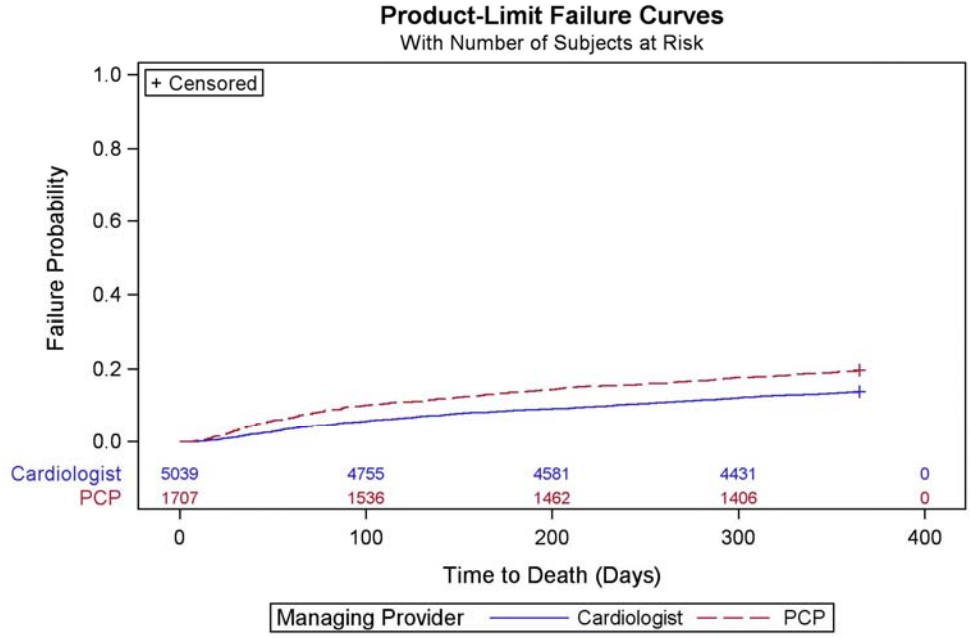

Schoen Macro Correlation of Covariates with Time to AVR:

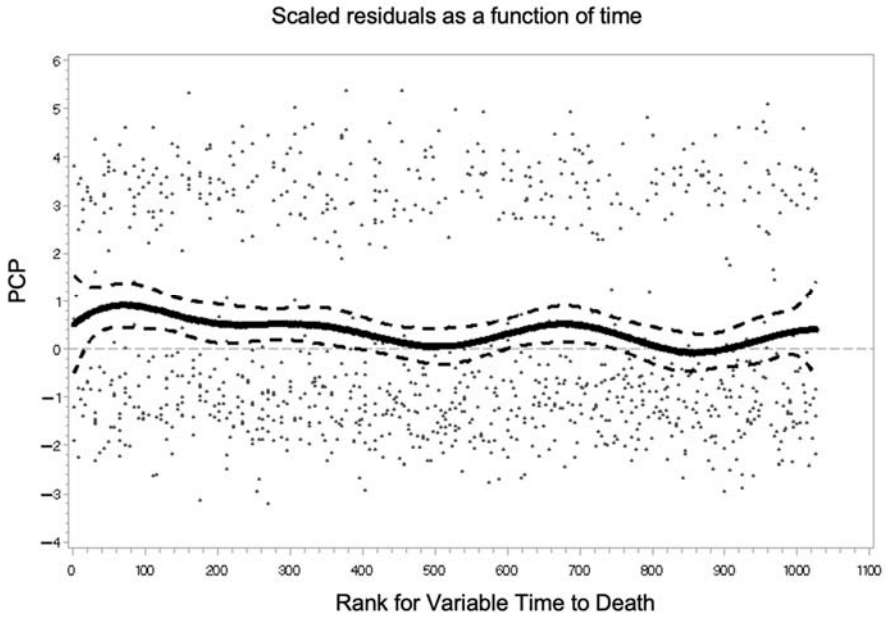
All correlations within =/-0.1

Managing Provider Correlation= -0.06829, p=0.0002

Abbreviations: AVR, aortic valve replacement; PCP, primary care provider

**Figure S3. Kaplan-Meier and Schoenfeld residual plots for mortality.**




Schoen Macro Correlation of Covariates with Time to Death:
All correlations within =/-0.1
Managing Provider Correlation= -0.07539, p=0.0156

Abbreviation: PCP, primary care provider