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ORIGINAL PAPER

Estimating the additional costs per life saved due to transcatheter aortic valve replacement: a secondary data analysis of electronic health records in Germany

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Abstract

Aortic stenosis (AS) is the most common valvular heart disease, with a dismal prognosis when untreated. Recommended therapy is surgical (SAVR) or transcatheter (TAVR) aortic valve replacement. Based on a retrospective cohort of isolated SAVR and TAVR procedures performed in Germany in 2015 ($N = 17{,}826$), we examine the impact of treatment selection on in-hospital mortality and total in-hospital costs for a variety of at-risk populations. Since patients were not randomized to the two treatment options, the two endpoints in-hospital mortality and reimbursement are analyzed using logistic and linear regression models with 20 predefined patient characteristics as potential confounders. Incremental cost-effectiveness ratios were calculated as a ratio of the risk-adjusted reimbursement and mortality differences with 95% confidence intervals obtained by Fieller's theorem. Our study shows that TF-TAVR is more costly that SAVR and that cost differences between the procedures vary little between patient groups. Results regarding in-hospital mortality are mixed. SAVR is the predominant procedure among younger patients. For patients older than 85 years or at intermediate and higher pre-operative risk TF-TAVR seems to be the treatment of choice. Incremental cost-effectiveness ratios (ICER) are most favorable for patients older than 85 years (ICER €154,839, 95% CI €89,163–€302,862), followed by patients at higher pre-operative risk (ICER €413,745, 95% CI €258,027–€952,273). A hypothetical shift from SAVR towards TF-TAVR among patients at intermediate pre-operative risk is associated with a less favorable ICER (€1,486,118, 95% CI €764,732–€23,692,323), as the risk-adjusted mortality benefit is relatively small (− 0.97% point), while the additional reimbursement is still eminent (+€14,464). From a German healthcare system payer's perspective, the additional costs per life saved due to TAVR are most favorable for patients older than 85 and/or at higher pre-operative risk.

Keywords Transcatheter aortic valve replacement · Surgical aortic valve replacement · Cost · ICER

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Introduction

Aortic stenosis (AS) is the most common valvular heart disease, with incidence increasing with age [1]. Prognosis is poor without valve replacement [2]. Recommended therapy for symptomatic patients or asymptomatic patients with severe AS is either surgical (SAVR) or transcatheter (TAVR) aortic valve replacement, depending on assessed surgical risk [3]. With surgical valve replacement, patients can expect a life expectancy only slightly lower than that of patients without AS [4]. Survival after TAVR is similar to that reported after SAVR [5–8]. However, TAVR continues to be the more expensive procedure even after taking into account the reduced length of hospital stay after the less invasive transcatheter procedure [9]. This factor tends to be disregarded in comparisons [10] of the procedures aimed at medical audiences, even as TAVR is assessed for use in patients at intermediate [11–13] or even low [8, 14] surgical risk.

The present study uses data from the German universal healthcare system to further improve our understanding of the economics of clinical practice. In Germany, hospitals are reimbursed on the basis of the German Diagnosis-Related Groups (G-DRG) system. Fees are adjusted yearly based on expenditure data from a sample group of German hospitals and are subject to continuous calibration to accurately reimburse cost [15–20]. These databases represent a valuable source of national-level health economic data that have been used previously to examine other disorders [21–23]. The data are highly detailed and include a wide range of patient characteristics and preexisting conditions. Using data from these sources, we examine the impact of treatment selection on in-hospital mortality and the total costs of the procedure for a variety of at-risk populations. Based on these results, incremental cost-effectiveness ratios (ICER) are calculated, showing at which amount of additional reimbursement a patient life could be saved.

Methods

Data

Since 2005, data on all hospitalizations in Germany have been available for scientific use via the Diagnosis-Related Groups (DRG) statistics collected by the Research Data Center of the Federal Bureau of Statistics (DESTATIS). These hospitalization data, including diagnoses and procedures, are a valuable source of representative nationwide data on the in-hospital treatment of patients. This database represents a virtually complete collection of all hospitalizations in German hospitals that are reimbursed according to the DRG system. From this database [24], we extracted data on 17,826 cases of isolated TAVR and SAVR procedures conducted in 2015. For TAVR, only cases via the transfemoral access route (TF-TAVR) were considered. As described previously [24, 25], patients with a baseline diagnosis of pure aortic regurgitation (main or secondary diagnosis other than I35.0, I35.2, I06.0, I06.2) and those with concomitant cardiac surgery or percutaneous coronary intervention were not included in this analysis. A complete list of procedure codes as well as a more detailed discussion of the validity of the data source may be found in a previous manuscript [24, 25], as well as in the supplementary appendix S1.

Our study did not involve direct access by the investigators to data on individual patients but only access to summary results provided by the Research Data Center. Therefore, approval by an ethics committee and informed consent were determined not to be required, in accordance with German law. All summary results were anonymized by DESTATIS. In practice, this means that any information allowing the drawing of conclusions regarding a single patient or a specific hospital are censored by DESTATIS to guarantee data protection. Especially the use of the anonymous, persistent "institute indicator of hospitals" is highly restricted to not publish any information directly attributable to a single hospital.

The analysis focuses on in-hospital mortality and actual reimbursement. In-hospital mortality and actual reimbursement were part of DESTATIS' main set of variables. For all comorbidities, the existing anamnestic or acute distinctive codes were used (we have discussed OPS and ICD codes in greater detail previously [25]). For calculation of the estimated logistic EuroSCORE, we were able to populate all fields except for critical pre-operative state and left ventricular function. In these we assumed an inconspicuous state (i.e., no critical pre-operative state and no left ventricular dysfunction) and thus calculated a best-case scenario. To allow a direct comparison of the baseline risk factor composition between TF-TAVR and SAVR patients, we calculated logistic EuroSCORE values assuming isolated SAVR procedures for both groups.

Statistical analysis

To identify the impact of treatment selection (TF-TAVR or SAVR) on the respective outcome, logistic and linear regression models were used for the endpoint in-hospital mortality and reimbursement, respectively. In a previous study, Reinöhl et al. [24] identified a number of baseline patient characteristics to describe risk profiles between procedural groups. Since patients were not randomized to the two treatment options (TF-TAVR or SAVR), all of these baseline patient characteristics were included as potential confounders (all covariates listed in Table 1). To account for the correlation of error terms of patients treated in the same hospital, a random intercept was included at the center level. Risk-adjusted mortality rates were obtained by computing the corresponding predicted probabilities for an artificial subject with each confounder set to its mean value (prediction at the means). Finally, the incremental cost-effectiveness ratio (ICER) was calculated as a ratio of the risk-adjusted reimbursement and mortality difference (additional reimbursement divided by excess mortality), with 95% confidence intervals obtained by Fieller's theorem [26]. To identify subgroups of patients in which one of the two treatment options (TF-TAVR or SAVR) might be preferable with respect to a specific outcome, patients age [27–29] and patients pre-operative risk assessed by the EuroSCORE [12] were used to define subgroups of interest in which the described analyses were conducted. All analyses

Table 1 Baseline characteristics

	AVR		TF-TAVR	
Patients, *n*	6226		11,600	
EuroSCORE (mean, SD)[a]	5.21	4.67	13.82	10.28
Age (mean, SD)	68.09	10.05	81.10	6.05
Women	37.44%		53.90%	
NYHA II	13.15%		10.24%	
NYHA III or IV	29.44%		47.03%	
CAD	19.02%		47.84%	
Hypertension	60.66%		63.66%	
Previous MI (within 4 months)	0.59%		1.53%	
Previous MI (within 1 year)	0.27%		0.64%	
Previous MI (after 1 year)	2.06%		3.91%	
Previous CABG	1.72%		8.69%	
Previous cardiac surgery	4.87%		14.06%	
PAD	4.93%		8.02%	
Carotid disease	4.02%		4.98%	
COPD	9.35%		13.07%	
Pulmonary hypertension	9.80%		20.97%	
GFR_lt15	0.84%		2.22%	
GFR_lt30	1.03%		4.14%	
Atrial fibrillation	39.43%		44.94%	
Diabetes	23.90%		31.95%	

[a]For calculation of the estimated logistic EuroSCORE, we were able to populate all fields except for critical pre-operative state and left ventricular function. In these we assumed an inconspicuous state (i.e., no critical pre-operative state and no left ventricular dysfunction) and thus calculated a best-case scenario

were carried out using Stata 14 (StataCorp, College Station, Texas, USA).

Results

Baseline characteristics and in-hospital outcomes

Between January and December 2015, 6226 isolated SAVR and 11,600 isolated TF-TAVR procedures were performed in Germany, for a total of 17,826 cases of isolated TAVR and SAVR procedures. In comparison to previous years [24], in-hospital mortality was low at 2.09% and 3.10%, respectively. Patient-specific reimbursement was substantially higher for TF-TAVR procedures (€33,936 compared to €19,055 for SAVR procedure, see Table 2). At the same time, TF-TAVR patients were older (81.10 versus 68.09 years, $p<0.001$), their pre-operative risk assessed by the logistic EuroSCORE was higher (13.82% vs 5.21%, $p<0.001$), and all other risk factors were impaired (see Table 1). Figure 1 also shows that SAVR is the predominant procedure among younger patients, while TF-TAVR is the treatment of choice for the older cohorts.

The impact of treatment selection on in-hospital mortality and reimbursement

Among younger patients (aged < 75 years), SAVR was the most common treatment strategy (4250 cases versus 1248 TAVR cases), and the risk-adjusted effect of treatment selection on in-hospital mortality was unclear ($p=0.345$, see Table 2). Patient-specific reimbursement was substantially higher for TF-TAVR procedures even after baseline risk-adjustment (€13,285 difference per case, $p<0.001$).

The same is true for patients aged 75–79 and patients aged 80–84, where TF-TAVR procedures outnumbered SAVR, but effect of treatment selection on in-hospital mortality was again unclear ($p=0.095$ and $p=0.154$, respectively.). For patients aged ≥ 85 years, TF-TAVR was associated with a lower risk for in-hospital mortality ($p<0.001$). At the same time, reimbursement was still substantially higher for TF-TAVR (€10,625 difference per case, $p<0.001$).

The same is true when categorizing patients according to their pre-operative risk assessed by the EuroSCORE: Among patients with EuroSCORE values < 4, SAVR was the dominating treatment strategy (3025 cases versus 405 TF-TAVR cases) and the treatment effect on in-hospital mortality was unclear ($p=0.072$). Patients at intermediate risk (EuroSCORE values ≥ 4 and ≤ 9), however, less often underwent SAVR (2263 versus 4,128 TF-TAVR cases), and the treatment effect on in-hospital mortality was eminent ($p=0.037$). Patients at higher risk (EuroSCORE values > 9), were most commonly treated with TAVR, which was associated with a lower risk for in-hospital mortality ($p<0.001$).

Additional costs per life saved due to TF-TAVR

TF-TAVR was associated with decreased mortality risk but increased patient-specific reimbursement in patients aged ≥ 85 years, at intermediate risk (EuroSCORE values ≥ 4 and ≤ 9) and at higher risk (EuroSCORE values > 9). To show at what cost a patient life could be saved, the incremental cost-effectiveness ratio (ICER) may be calculated. As shown in Table 2, the hypothetical shift from SAVR towards TF-TAVR is associated with an ICER of €154,839 (CI €89,163–€302,862) for patients at high age and an ICER of €1,486,118 (CI €764,732–€23,692,323) and €413,745 (CI €258,027–€952,273) for patients at intermediate and higher risk, respectively. In addition, ICER for younger patients is comparatively high (€1,473,726 for patients aged 75–79 and €1,127,791 for patients aged 80–84).

Table 2 Comparison of costs between TF-TAVR and AVR

		AVR		TF-TAVR		Unadjusted difference			Risk-adjusted difference			Additional costs per life saved due to transcatheter aortic valve replacement	
						dy/dx	p Value	95% CI	dy/dx	p Value	95% CI	iCER	95% CI
All patients													
	N (reimbursement/ mortality)[a]	6105	6226	11,546	11,600								
	In-hospital mortality, %	2.09%		3.10%									
	Reimbursement[a] (mean, SD)	19,055 €	11,976 €	33,936 €	6601 €								
By age													
< 75	N (reimbursement/ mortality)[a]	4165	4250	1237	1248								
	In-hospital mortality, %	1.48%		2.48%		0.95%	0.017	0.17–1.73%	− 0.41%	0.345	− 1.25–0.44%		
	Reimbursement[a] (mean, SD)	18,888 €	11,581 €	34,412 €	9222 €	15,487 €	0.000	14,695–16,279 €	13,285 €	0.000	12,485–14,085 €		
75–79	N (reimbursement/ mortality)[a]	1474	1502	2827	2833								
	In-hospital mortality. %	2.93%		2.54%		− 0.36%	0.497	− 1.38 to 0.67%	− 0.95%	0.095	− 2.06–0.16%		
	Reimbursementa (mean, SD)	19,411 €	13,394 €	33,937 €	6293 €	14,437 €	0.000	13,571–15,304 €	13,937 €	0.000	12,954–14,920 €	1,473,726 €	b
80–84	N (reimbursement/ mortality)[a]	413	421	4164	4186								
	In-hospital mortality, %	3.33%		3.01%		− 0.55%	0.557	− 2.38 to 1.28%	− 1.32%	0.154	− 3.13–0.49%		
	Reimbursement[a] (mean, SD)	18,938 €	10,195 €	33,944 €	6677 €	14,972 €	0.000	13,824–16,119 €	14,854 €	0,000	13,681–16,028 €	1,127,791 €	b
≥ 85	N (reimbursement/ mortality)[a]	53	53	3318	3333								
	In-hospital mortality, %	16.98%		3.93%		− 6.51%	0.000	− 9.66 to 3.35%	− 6.86%	0.000	− 10.01 to − 3.72%		
	Reimbursement[a] (mean, SD)	23,210 €	12,966 €	33,748 €	5493 €	10,566 €	0.000	7052–14,079 €	10,625 €	0.000	7,098–14,153 €	154,839 €	89,163–302,862 €

Table 2 (continued)

		AVR		TF-TAVR		Unadjusted difference			Risk-adjusted difference			Additional costs per life saved due to transcatheter aortic valve replacement	
						dy/dx	p Value	95% CI	dy/dx	p Value	95% CI	iCER	95% CI
By Euroscore													
<4	N (reimbursement/ mortality)[a]	3025	3095	405	410								
	In-hospital mortality, %	0.87%		2.20%		1.21%	0.009	0.30–2.13%	0.85%	0.072	− 0.08 to 1.77%		
	Reimbursement[a] (mean, SD)	17,828 €	7795 €	33,285 €	3,464 €	15,421 €	0.000	14,870–15,972 €	14,815 €	0.000	14,108–15,521 €		
≥ 4 to ≤9	N (reimbursement/ mortality)[a]	2263	2305	4128	4,154								
	In-hospital mortality, %	2.65%		2.07%		− 0.46%	0.260	− 1.26 to 0.34%	− 0.97%	0.037	− 1.89 to − 0.06%		
	Reimbursement[a] (mean, SD)	19,176 €	12,745 €	33,614 €	6672 €	14,524 €	0.000	13,800–15,248 €	14,464 €	0,000	13,670–15,258 €	1,486,118 €	764,732–23,692,323 €
>9	N (reimbursement/ mortality)[a]	817	826	7013	7036								
	In-hospital mortality, %	5.08%		3.77%		− 1.34%	0.057	− 2.72 to 0.04%	− 2.56%	0.000	− 4.01 to 1.12%		
	Reimbursement[a] (mean, SD)	23,265 €	19,342 €	34,163 €	6687 €	10,699 €	0.000	9242–12,157 €	10,606 €	0.000	9,158–12,054 €	413,745 €	258,027–952,273 €

[a]For a number of patients, reimbursement data were unavailable

[b]Since the confidence interval of the denominator includes zero, it is not possible to compute the CI of the quotient

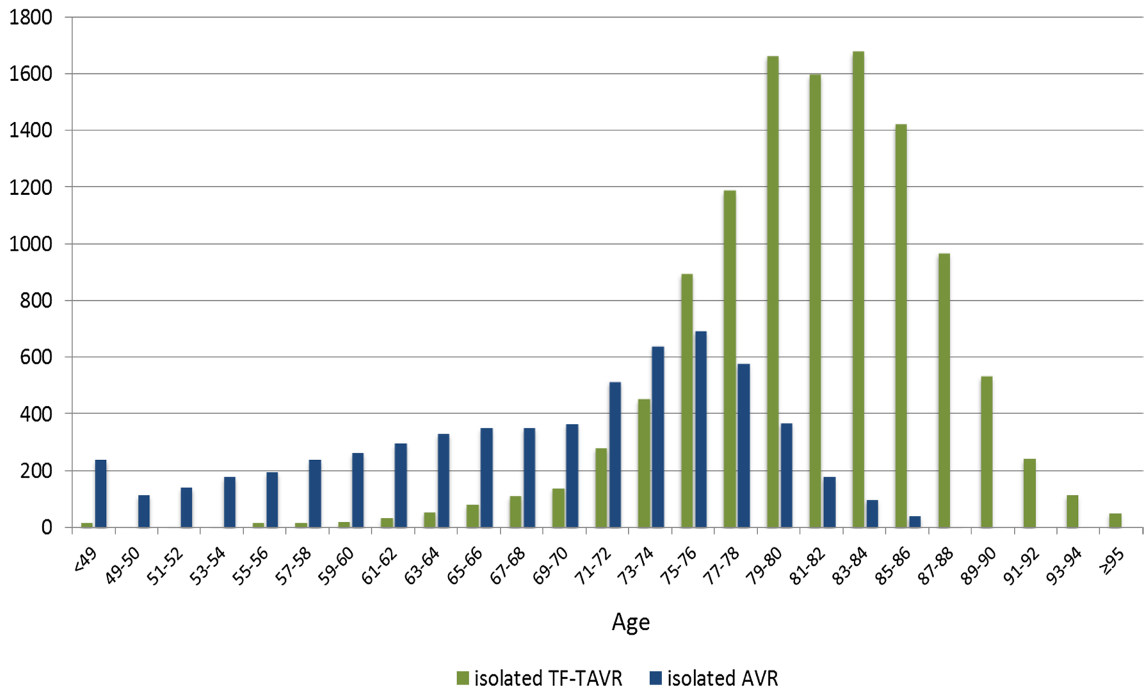

Fig. 1 Procedure numbers by age

Discussion

In the years following the introduction of a new procedure, a major improvement in its quality can generally be observed. Since, however, the patient-selection criteria for novel procedures can also be subject to rapid change, straightforward observations of the temporal evolution of quality criteria are often incomplete. TF-TAVR is still a relatively young technique, especially when compared to the direct alternative, SAVR, and the development of outcomes since its introduction is in part result of a noticeable learning curve [30, 31]. This means that treatments effects retrospectively vary depending on the exact year of the intervention, and as a result studies or trials performed over a relatively short timeframe provide a snapshot that can be misleading or outdated a short time later. For 2015, our study shows that TF-TAVR is more costly that SAVR and that cost differences between the procedures vary little between the different patient groups. At the same time, results regarding in-hospital mortality are mixed: For patients older than 85 years or at intermediate and higher pre-operative risk TF-TAVR seems to be the treatment of choice. In combination with the higher reimbursement, the additional costs per life saved are most favorable for patients older than 85 years (ICER €154,839) followed by those patients at higher pre-operative risk (ICER €413,745). A hypothetical shift from SAVR towards TF-TAVR among patients at intermediate pre-operative risk is associated with a less favorable ICER (€1,486,118), as the risk-adjusted mortality benefit is relatively small (− 0.97 percentage point), while the additional reimbursement is still eminent (+€14,464).

Our study has several limitations, beyond those normally associated with a retrospective analysis [24]. First, it is based on administrative data. As a consequence, coding errors are inevitable. The documentation of NYHA in German claims data, for example, are often imprecise. As a result, risk-adjustment included a number of parameters whose reliability cannot be fully secured, and we cannot guarantee that all parameters of relevance are included in the model. Moreover, the administrative dataset lacks relevant clinical information (such as echocardiographic findings or anatomical characteristics), preventing operative risk assessment or a better understanding of the underlying valvular pathomechanism. Therefore, only an approximation of the logistic EuroSCORE—in fact a conservative or ‘best-case scenario’ estimate—is applied. When estimating treatment effects, adjusted differences in in-hospital outcomes may be interpreted as procedure-related effects if all decision- and outcome-relevant parameters are used for risk-adjustment. Unfortunately, we cannot guarantee that all parameters of relevance are included in the model. Finally, the dataset omits patients with a baseline diagnosis of pure aortic regurgitation, as well as those who underwent TF-TAVR or SAVR with any other concomitant cardiac procedure. This makes sense from a clinical perspective, but further complicates direct comparisons with other administrative datasets.

Overall, our results show that the question of the cost-effectiveness of TAVR in different populations returns a varied picture. From a German healthcare system payer's perspective, our results show that the additional costs per life saved are most favorable for patients older than 85 and/or at higher pre-operative risk. For patients aged 75–84 and/or at intermediate pre-operative risk, however, the additional costs per life saved due to TAVR are much higher (more than one million €). Given that TAVR is still a relatively young technique with an ongoing learning curve, discussions regarding treatment selection among these patient groups will remain active for the coming years.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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