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Economic Evaluation

Reimbursement Savings Associated With Tissue Versus Mechanical Surgical Aortic Valve Replacement in Thailand

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ABSTRACT

Objectives: Surgical aortic valve replacement (SAVR) is an indicated treatment for severe aortic stenosis. Although mechanical valves are typically more durable, tissue SAVR valves do not require lifetime anticoagulation monitoring and may have lower rates of expensive sequelae. This economic evaluation estimates payer costs to the 3 largest Thai health insurance mechanisms for tissue versus mechanical SAVR.

Methods: A deterministic and Monte Carlo simulation model based on literature and expert opinion estimated total payer costs for tissue and mechanical valves over a 25-year duration for 3 separate age cohorts (45, 55, and 65 years). Reimbursements levels for hospitalization services were from the Thai Diagnosis Related Groups. Separate models are generated for the 3 main Thai health insurance mechanisms.

Results: The discounted expected 25-year reduction in payer savings associated with tissue SAVR are $2540, $2529, and $2311 per surgery for patients aged 45, 55, and 65 years, respectively, for the largest Thai insurer. Expected cost reductions associated with tissue SAVR are larger for each of the other schemes and generally decrease with patient age. Most savings accrue within 10 years of surgery. Reoperation costs are larger with tissue valves, but reductions in complications and anticoagulation monitoring more than offset these expenditures. Results are robust to multiple sensitivity and scenario analyses.

Conclusions: Coverage and reimbursement of tissue valves can financially benefit Thai insurers and reduce expenditures in the Thai health system compared with mechanical valves. As tissue valve technology evolves and reoperation rates decline, the financial benefit associated with tissue valves will increase.

Keywords: health economics, health systems policy, reimbursement, surgical aortic valve replacement.

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Introduction

As epidemiological transitions occur and life expectancies increase in middle-income Asian nations, moderate to severe aortic stenosis (AS) is increasingly prevalent, and in some instances, Asian rates are similar to those found in Europe and North America (3% or more in select age cohorts).[1,2] Thailand, with a population of approximately 70 million and an increasing share of elderly, aims to provide high value care in its social health insurance system.[3] Government payers cover >76% of health expenditures in Thailand ($276 per capital annual health expenditure), and complex cardiovascular conditions such as AS are expensive to treat. In addition, newer technologies, such as tissue surgical aortic valve replacement (SAVR), are potentially more likely to get shifted to out-of-pocket (private) payments in middle-income countries with heavy reliance on government financing, so understanding the financial savings attributable to payers can help improve government-based coverage and reimbursement for newer technologies and increase uptake, especially in lower income groups. As such, policy makers for the 3 insurance mechanisms in Thailand (Universal Coverage Scheme [UCS], 75% of the Thai population; Social Health Insurance [SHI], 16%; and Civil Servant Medical Benefit Scheme [CSMBS], 9%) may benefit from an understanding of the long-term financial impact associated with tissue versus mechanical SAVR, 2 options indicated for treatment of AS.[4-7] With an understanding of the long-term financial impact, Thai insurers can identify how investments in appropriate technology today can lead to a more sustainable financial profile of health expenditures going forward.

Trade-offs between the 2 SAVR options include prosthetic durability, risk of reoperation, hemodynamics, thrombogenicity, patient life expectancy, and lifestyle considerations (such as preference for avoiding anticoagulation monitoring because of the higher risk of bleeding with physical activity/contact sports, limitations on certain foods such as leafy green vegetables, and restrictions on certain “over-the-counter” medications such as ibuprofen).[8-22] Generally, tissue valves have a higher risk of reoperation but mechanical valves require lifelong anticoagulation and generally have higher risk of bleeding and thromboembolism. As sequelae related to SAVR occur over decades, a long-term economic evaluation can provide guidance for the Thai Ministry of Public Health and other relevant Thai ministries (such the National Health Security Office that oversees purchasing for UCS, the Comptroller General Department within the Ministry of Finance that directs financing for CSMBS, and the Social Security Offices that administers the SHI program) as they seek to understand the financial impact associated with tissue versus mechanical SAVR. A recent Monte Carlo simulation compared healthcare expenditures associated with the use of tissue versus mechanical prostheses over a 25-year period in the United States.[23] Nevertheless, this Thai economic analysis focuses on reimbursement payments primarily derived from the Thai Diagnosis Related Groups (DRGs) to evaluate Thai payer costs, rather than out-of-pocket, hospital, or overall costs. This study takes the perspective of the payer (Thai government) rather than a social perspective (as in the US study). As such the term "cost" in the context of this analysis will generally be synonymous with "reimbursement" unless otherwise specified.

The purpose of this economic study is to assess the expected difference in healthcare costs incurred by Thai payers associated with tissue versus mechanical SAVR in Thailand over a range of time horizons (from 30 days to 25 years) and scenarios. Our simulation model applies a similar structure as in the previous US effort, but relies on Thai data to estimate inputs that determine health expenditures in 2 synthetic cohorts of Thai SAVR patients (tissue vs mechanical) over time. We also examine specific scenarios that may more closely reflect the financial impact given improvements in technology over time.

Methods

This financial model follows published guidance for economic evaluations in healthcare (Consolidated Health Economic Evaluation Reporting Standards methodology) and recommendations for adaption of models across geographies.[24-26] The study adopts a Thai payer perspective and focuses on reimbursement (or payer costs) related to SAVR procedures and related sequelae.

The structure of the model is similar to the US case—first, we assumed equally sized synthetic cohorts for (1) "mechanical SAVR" and (2) "tissue SAVR" patients (n = 10 000 each).[23] Both sets of patients were assigned a specific age of initial SAVR surgery (45, 55, or 65 years) given that 3 separate previous studies estimated long-run outcomes that map to each of these age groups. As such, savings estimates can differ by age cohort. Although it would be optimal to have some even older age cohorts (eg, 75 or 85 years), the long-term cohort studies did not provide sufficient detail to develop a model for older age groups. The model ran for 25 years after initial SAVR and accounts for mortality and 5 other clinical events associated with SAVR within each period (conditional on survival). These events are (1) reoperation, (2) bleeding or hemorrhagic event, (3) thrombosis, (4) endocarditis, and (5) anticoagulant monitoring (ACM) (required for life in the case of mechanical SAVR or assumed to last 3 months in the case of tissue SAVR). Stroke was excluded because both bleeding/hemorrhage and thrombosis events potentially overlap with stroke events and inclusion of stroke could result in "double counting." Given that these events are more common in mechanical valve SAVR populations, this assumption is a conservative one (we are less likely to find cost savings associated with tissue valves as a result). Within each time period, total SAVR-related expenditures were calculated by multiplying the expected number of events occurring in each group by the discounted cost per event.

Clinical Events

We estimated the probability of each clinical event occurring in the first 30 days after the initial SAVR surgery and every year thereafter over a 25-year horizon. The model assumes tissue SAVR patients undergo ACM for 3 months after surgery, but mechanical SAVR patients require ACM for life. To the extent that SAVR tissue valve patients conclude their ACM earlier than 3 months, this 3-month assumption is conservative. For each period, the probability of events was multiplied by the number of survivors to estimate the number of medical events that occurred in each age group (the Appendix in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003 provides details and the equations used to estimate both probabilities and event numbers). Input probabilities for mortality and key outcomes in the tissue SAVR group over each of the 25 years were generated from Kaplan-Meier survival estimates reported in 3 cohort studies, each of which tracked a distinct age cohort after receiving one of the most commonly used tissue aortic valve replacement repair products—the Carpentier-Edwards PERIMOUNT® aortic valve.[9-11] Although we would ideally prefer to use Thai-specific data for the health outcome probabilities, long duration outcomes data do not exist for tissue or mechanical SAVR patients in the Thai health system. As such our base case models for 45-year-old, 55-year-old, and 65-year-old cohorts rely on inferred rates from 3 French studies.[9-11] Nevertheless, in a sensitivity analysis, we adjust for Thai age-specific mortality rates (relative to France mortality rates from the reference studies) to estimate mortality probability over time in the Thai tissue SAVR cohort. We run an analysis for each of the 3 age cohorts given that (1) there are different rates of sequelae as age increases, (2) the longer life expectancy in younger cohorts may increase the likelihood of costly reoperation at some point in the future, and (3) we maintain consistency with the previously published and validated US study.

The event and mortality probabilities for each period in the tissue SAVR cohort were multiplied by hazard ratios (HRs) from 2 recent meta-analyses that compare tissue and mechanical risks to calculate an analogous set of probabilities for the mechanical SAVR group (Table 1,[22,27] Appendix Table 1 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). This approach assumes that the HR is a reasonable proxy for relative risk and that the relative risk remained constant over time and across age groups. In select sensitivity analyses, we adjusted HRs to identify their impact on the magnitude of savings to the Thai healthcare system.

Reimbursement and Payer Costs

In the primary analysis, reimbursement per event (Table 1[22,27]) was estimated for each of the 3 major insurance systems in Thailand (UCS, SHI, and CSMBS) by multiplying the DRG relative weight (RW) units for each event by the appropriate reimbursement amount per RW unit (these differ across each insurer). DRG RW estimates were sourced from the Thai DRG Version 6.3.3 (CSMBS and SHI) and Thai DRG Version 5.1 (UCS).[28,29] Given that there were multiple DRG RW estimates for each outcome (typically between 3 and 5 RW values per DRG depending on the severity of complications or patient characteristics), the base case analysis relied on the median estimate (see Appendix Tables 2-4 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003 for details). In sensitivity analyses, we also use the maximum and minimum DRG RWs. Given that there were separate DRGs for intracranial and gastrointestinal bleeding, we estimated that 28% of bleeding were intracranial and the rest were gastrointestinal on the basis of previous literature in similar clinically relevant Thai patient populations.[30] DRG payments only

Table 1. Base case hazard ratios (tissue vs mechanical SAVR) and estimated reimbursements for select clinical events.

Clinical event	Hazard ratio*	Estimated reimbursement ($US 2020; median DRG, by insurer type),†,$		
		UCS	CSMBS	SHI
Mortality	1.21	N/A	N/A	N/A
SAVR operation/reoperation	2.19	4057	5922	7441
Thromboembolism	0.54	593	605	760
Bleeding/hemorrhage	0.48	954	2480	3117
Endocarditis	1.61	441	1419	1782
Anticoagulant monitoring (annual)	N/A‡	225	300	405

Note. A complete set of model inputs, sources and additional discussion are available in the Appendix (see Appendix Table 1 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003).
ACM indicates anticoagulant monitoring; CSMBS, Civil Servant Medical Benefit Scheme; DRG, Diagnosis Related Group; N/A, not available; SAVR, surgical aortic valve replacement; SHI, Social Health Insurance; UCS, Universal Coverage Scheme.
*Hazard rates reflect the risk of event for tissue valve divided by the risk of event for mechanical valve for mortality; reoperation, thromboembolism, and bleeding/hemorrhage are sources from Zhao et al.[22] The estimate for endocarditis is based on Brennan et al.[27]
†Exchange rate (International Monetary Fund, July 1, 2020; https://www.imf.org/external/np/fin/data/param_rms_mth.aspx) is estimated at 30.95 TBH per $1 US (2020, current).
‡ACM costs are assumed to occur for the first 6 months postsurgery for tissue valve patients, but for the rest of one's life for mechanical valve patients.

differentiate on the basis of patient complexity among each of the Thai insurers; as such we assume that the reimbursed DRG payments for both tissue and mechanical SAVR are the same.

The payment per RW unit differed across insurers and was based on either (1) a review of Thai Ministry of Health Annual Reports (used in the "base case" estimate) or (2) expert opinion from a DRG specialist in Thailand (sensitivity analysis) (Appendix Table 5 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003) (Personal communication, Bunchai Chongmelaxme, March 9, 2021). The RW values from the expert were comparable with estimates calculated by dividing the Thai MOH annual hospital expenditures by Thai hospitalizations (by insurer) as reported in previous MOH annual reports (a mean hospitalization is approximately scaled so that it should roughly equal to one RW unit). We updated payment per RW estimates to 2020 current Thai baht using an estimated Thai inpatient healthcare inflation rate of 2.6% (between the index year and 2020) on the basis of recent hospital prices in the World Bank International Comparison Program surveys (for the relative growth in inpatient price growth in the US and Thailand) and the US Bureau of Economic Analysis inpatient price growth over the relevant period. SHI, the social insurance mechanism that typically uses funding from government, employers, and employee contribution, typically pays the highest rate per DRG RW unit (see Appendix Table 5 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003) followed by the tax-funded civil service system (CSMBS) and UCS (also tax funded). For additional details on the DRG weights used, see the "DRG RW reimbursement" section in the Appendix in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003. Going forward, the model applies a 3% discount rate and 3% medical inflation rate for expected healthcare costs in the base case.

In addition to event costs, the model accounts for the annual cost of anticoagulation medication and monitoring (ACM) over time. In particular, it relies on a recent study conducted in Thailand that assumed 20 International Normalized Ratio tests per year at 82.6 baht ($2.67) per test, pharmacist service costs of 480 baht ($15.51) per quarter, and medication costs (warfarin) of 250 baht ($8.08) per month.[31] Nevertheless, to better reflect variations in real-world practice, we also conducted a sensitivity analysis, which assumes a lower frequency of ACM visits (4 per year rather than 20 per year) and reduced costs for warfarin (150 baht per month in 2020 baht). For each health insurer, we scaled the overall ACM annualized costs in proportion with the weighted average of the reimbursement per RW unit across insurers.

Model Types

The base case "deterministic" model calculates the total discounted SAVR-related costs in both patient groups for each time period (first 30 days, annually thereafter), based on the average expected values (or means) of the clinical probability and cost inputs. Given that Kaplan-Meier estimates adjust for mortality and follow-up, our model accounts for survival. Expenditures are summed over time across different durations (from any period between 30 days and 25 years) for each patient group. The economic model is payer specific for each of the 3 main Thai insurers (UCS, CSMBS, and SHI).

In addition to a deterministic model, "stochastic" Monte Carlo simulations were conducted to account for uncertainty of the inputs and provide confidence intervals (CIs). The summary of the means and distribution types for "stochastic" inputs is presented in Appendix Tables 1 and 6 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003 (costs). Each simulation included 10 000 trials. In each of the 10 000 trials, an output value was determined based on the random draws from each of the input distributions. The mean and median (5000th) output value were estimated, and the 250th and 9750th estimates define our 95% CI for the output. 95% CIs that did not include $0 were considered statistically significant. Sensitivity analyses highlight the key determinants that drive our central outcome—the difference in cumulative SAVR-related healthcare costs per person between the tissue and mechanical patient groups. Sensitivity analyses focused on key clinical variables that are likely to shift in the future—mortality and reoperation risk. Within the context of a financial model that measures morbidity, improvements in mortality and reoperation performance have countervailing effects on tissue SAVR payer costs—fewer deaths likely will increase SAVR-related insurance payments at the population level, but fewer reoperations will decrease total payer expenditures. Given the importance of ACM costs, we also conduct a "breakeven" analysis that identifies the minimum ACM annual cost at which 25-year savings for tissue valves equal to zero. All models were conducted using @Risk v8.2 within Microsoft Excel v16 (Microsoft Corporation, Redmond, WA). Separate models were developed for patients receiving SAVR at 45, 55, and 65 years old.

Results

Base Case Long-Run Estimate

In the base case model, tissue valves yield lower cumulative costs for each of the 3 Thai insurers relative to mechanical valves over 25 years (Table 2). This result holds for each of the 3 age cohorts, but as the age of initial surgery increases, the cost savings associated with tissue valves stay relatively constant or decrease slightly. Savings track with reimbursement rates across insurers—

Table 2. The 25-year mean (SD) savings per initial SAVR operation at median DRG rates (base case, by insurer type, $US 2020).

Age at initial SAVR operation	Insurance type, $		
	UCS (75% of Thai population)	CSMBS (9% of Thai population)	SHI (16% of Thai population)
45	2540 (232)	3219 (330)	4522 (422)
55	2529 (219)	3280 (309)	4533 (398)
65	2311 (219)	3037 (306)	4157 (397)

Note. SDs are derived from stochastic models. The means are based on the deterministic models.
CSMBS indicates Civil Servant Medical Benefit Scheme; DRG, Diagnosis Related Group; SAVR, surgical aortic valve replacement; SHI, Social Health Insurance; UCS, Universal Coverage Scheme.

SHI has the largest savings followed by CSMBS and then UCS. Overall, the expected 25-year discounted cumulative SAVR-related payer savings for a 45-year-old UCS patient are $2540 lower (95% CI $2107-$3014) with a tissue valve relative to a mechanical replacement (Fig. 1). For 45-year-olds in CSMBS, payer savings are $3219 lower (95% CI $2602-$3886) (Appendix Fig. 1.A in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). In SHI, assuming a 45-year-old patient remains in the program over the duration of the 25 years, savings for the insurer are $4522 (95% CI $3774-$5356) (Appendix Fig. 1.B in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). Across all 9 age group-insurer combinations, >99% of the simulations yielded cost savings favoring tissue valves over 25 years.

Impact Over Time

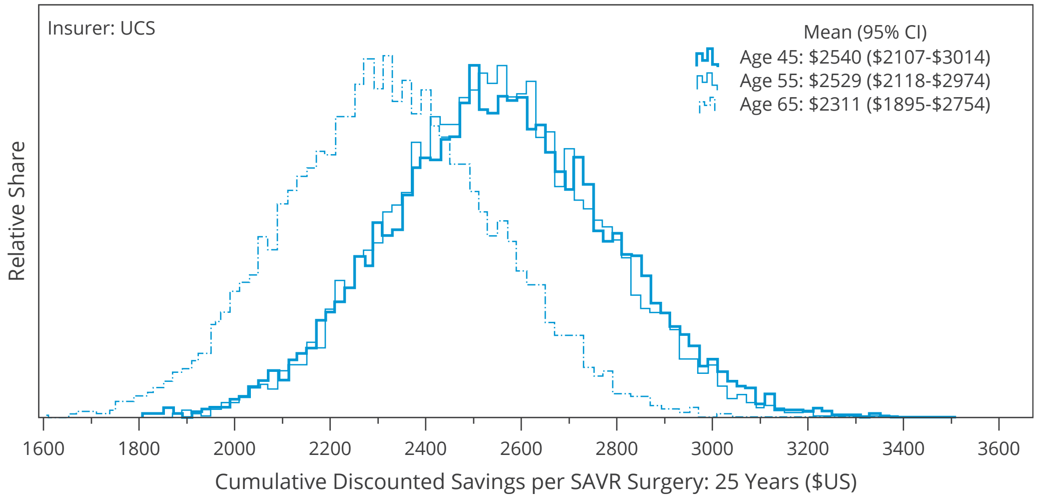
Payer savings associated with the use of tissue valves were generated in a relatively short time frame in the base case—usually 60% to 70% of long-run savings accrue within 10 years after surgery. For example, UCS expected savings for a 45-year-old SAVR patient exceed $1500 at 10 years (Fig. 2). Afterward the net savings continue to increase, albeit at a lower annual rate. Both CSMBS and SHI also show similar patterns although the savings are larger relative to UCS across each of the age groups (Appendix Fig. 2.A,B in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). For example, CSMBS savings exceed $2000 and SHI savings eclipse $2800 at the 10-year mark for a 45-year-old. By year 15, >85% of the long-run savings have accrued across all age/insurance dyad combinations (Appendix Table 7 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003).

Sensitivity Analyses

The probabilistic sensitivity analysis highlights the key inputs that influence the savings outcome in the stochastic model after accounting for input distribution characteristics. Over a 25-year period for a 45-year-old in UCS, the savings are most sensitive to the variation in (1) the mortality rate HR (tissue vs mechanical valve), (2) the reoperation hazard rate, and (3) the cost of a SAVR operation (Appendix Fig. 3.A in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003, Appendix Table 8 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). Similar results applied for the 55 year old cohort (see Appendix Figure 3.B in Suppliemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). Of the clinical sequalae, thromboembolism hazard rate was the most influential factor. The influence of the mortality HR had a more muted impact on variation in savings for the oldest cohort (but was still fourth, following SAVR operation costs for tissue and mechanical valves) (Appendix Table 8 and Appendix Figure 3.C in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). Similar results also held for the CSMBS and SHI insurance. The relevance of these variables, mortality hazard, reoperation hazard, and SAVR cost, is critical for the comparative estimation of costs and savings between both strategies.

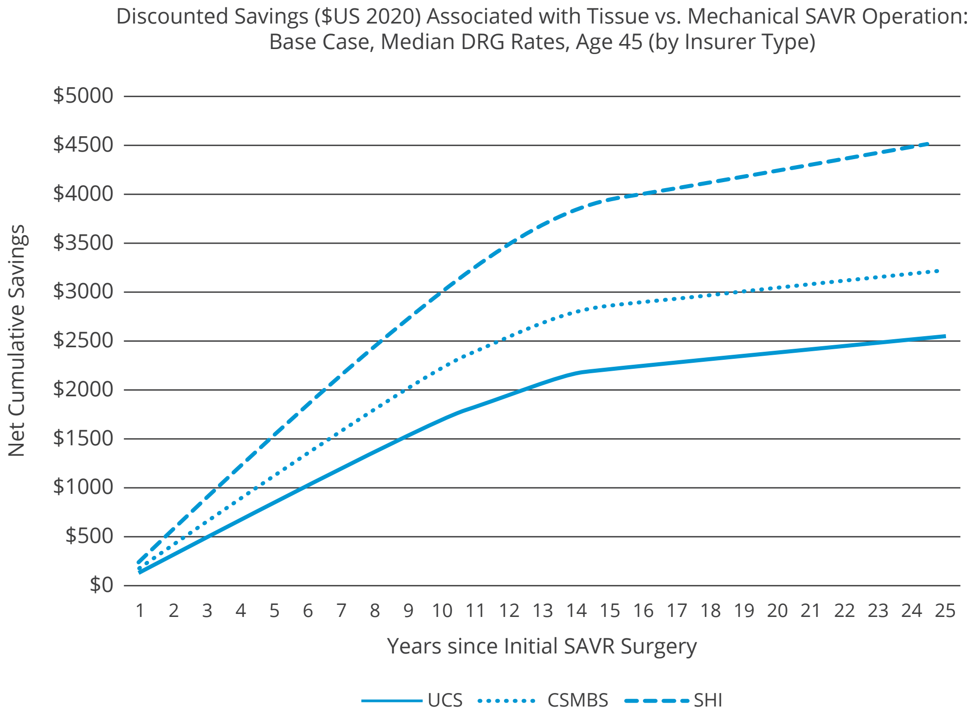
Given that anticoagulation monitoring costs are assumed fixed in the model, these are not detected with a probabilistic sensitivity analysis. Another useful way to evaluate savings is by disaggregating net savings (or costs) based on each of the clinical

Figure 1. Distribution of expected 25-year savings per initial tissue SAVR operation at median DRG rates for UCS patient ($US 2020, 10 000 simulations per age cohort).



CI indicates confidence interval; DRG, Diagnosis Related Group; SAVR, surgical aortic valve replacement; UCS, Universal Coverage Scheme.

Figure 2. Savings per initial SAVR operation at median DRG rates at age 45 years (by insurer type, $US 2020).



CSMB, Civil Servant Medical Benefit Scheme; DRG indicates Diagnosistic Related Group; SAVR, surgical aortic valve replacement; SHI, Social Health Insurance; UCS, Universal Coverage Scheme.

events (reoperation, thromboembolism, bleeding, endocarditis, and anticoagulation monitoring costs) and standardizing these by dividing each category total by total net savings. Appendix Table 9 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003 lists the overall savings and for each clinical event in the base case 25-year model. This analysis shows that the reoperation costs (which reduce net savings associated with tissue SAVR) and ACM costs (which increase net savings associated with tissue SAVR) are the key clinical drivers of overall savings. For example, in the base case for a 45-year-old in UCS, savings associated with ACM are $3765 per SAVR procedure whereas reoperation reduces net savings by $1309. Similar results occur in the CSMBS and SHI reimbursement schemes. As age increases, the relative importance of ACM and reoperation costs attenuate slightly, but these 2 events continue to have the largest influence over net savings.

Scenario and Breakeven Analyses

To identify expected savings under various assumptions, we conducted specific sensitivity or scenario analyses that typically alter one or 2 assumptions or inputs at a time, but retain the rest of the base case input values. For example, recent data on improved tissue valves suggest that the mortality hazard rates for tissue and mechanical valves are closer to unity (hazard rate 1.00).[32] As such we ran an analysis in which we assume the mortality of tissue valves drops to the level for mechanical valves. Under this condition, the savings associated with tissue valves are attenuated. For a 45-year-old in UCS, savings shift from $2540 to $2233 (Appendix Table 10 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). This result was similar for each of the insurer-age group dyads as savings declined between approximately $300 and $550 per surgery relative to the base case results.

Advances in tissue valve technology include novel valves with superior anticalcification properties that will likely also result in lower reoperation rates below the estimate used in the base case analysis (base case reoperation hazard rate 2.1).[33-36] In a scenario analysis in which both the mortality and reoperation rates are adjusted downward to the level of mechanical valves, the net effect is an increase in payers savings across all insurer-age group cohorts (Table 3). A UCS patient aged 45 years at initial SAVR surgery will generate $3843 in savings for a tissue valve relative to a mechanical valve. Generally, saving increases were in the range

Table 3. Scenario analysis for equivalent mortality and reoperation rates: 25-year mean savings per initial SAVR operation at median DRG rates (by insurer type and age of initial SAVR surgery, $US 2020).

Age at initial SAVR operation	Insurance type, $		
	UCS (75% of Thai population)	CSMBS (9% of Thai population)	SHI (16% of Thai population)
45	3843 (138)	5118 (194)	6908 (249)
55	3345 (139)	4468 (194)	6027 (250)
65	2776 (135)	3713 (187)	5006 (240)

Note. SDs are derived from stochastic models. The means are based on the deterministic models.
CSMBS indicates Civil Servant Medical Benefit Scheme; DRG, Diagnosis Related Group; SAVR, surgical aortic valve replacement; SHI, Social Health Insurance; UCS, Universal Coverage Scheme.

of 20% to 40% larger than the base case if one assumes parity for both mortality and reoperation. Parity in reoperation rates likely represents a "better case" scenario for tissue valves; as such we also examined savings if the reoperation rate is 50% higher (see Appendix Table 11 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003) in a tissue valve relative to mechanical valves (vs 110% higher in our "base case" model). Savings in this "50%" model generally are close to the midpoint of the savings found in the base case model and the model in which mechanical valve and tissue valve are assumed to have equivalent mortality and reoperation performance.

The base case analysis assumes that the DRG severity is the median level for each of the clinical outcomes. If we assume patients are relatively complex (we use the highest DRG level for each outcome), the net savings generally are lower, but are within $100 of the base case values across each age cohort and insurer type over 25 years (Appendix Table 12 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). For example, for a 45-year-old in UCS the savings decrease from $2540 to $2458 if the patient is higher acuity. Lower acuity patients generally yield higher savings for Thai insurers, but the expected increase in savings associated with tissue valves is modest across all age and insurer types (Appendix Table 13 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003).

How low could annual ACM costs decline before the savings associated with tissue valves are reduced to $0? The "breakeven" analysis (see Appendix Table 14 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003) reflects the amount below which tissue valves would become more costly than mechanical SAVR valves. The amount depends on age cohort and insurer, but generally falls between 10% and 40% of the current expected reimbursed cost. For a 45-year-old in UCS (where estimated annual ACM monitoring costs are $225 per annum), savings reach $0 if annual ACM costs are $73 if all other variables remain at base case values. In older age cohorts, the decline must be even more extreme—for a patient receiving SAVR at age 65 years in UCS, the annual cost would have to be <$32 per annum. We also incorporated a sensitivity analysis in which lower frequency of International Normalized Ratio testing annual visits (4 vs 20 in the base case) and lower medication costs for warfarin were assumed (180 Thai baht [2020] rather than 230 Thai baht [2013]) (Table 4). The savings do decline but 25-year savings still range from between $1200 and $1800 across all age-insurer dyads.

Table 4. Scenario analysis for reduced INR testing frequency and lower ACM medication costs: 25-year mean savings per initial SAVR operation at median DRG rates (by insurer type and age of initial SAVR surgery, $US 2020).

Age at initial SAVR operation	Insurance type, $		
	UCS (75% of Thai population)	CSMBS (9% of Thai population)	SHI (16% of Thai population)
45	1302 (213)	1573 (304)	2297 (387)
55	1459 (194)	1858 (276)	2612 (353)
65	1427 (187)	1862 (264)	2568 (340)

Note. The means are based on the deterministic models. This analysis assumes INR testing is checked quarterly and monthly medication cost is 180 Thai baht (2020 TBH).
ACM indicates anticoagulation medication and monitoring; CSMBS, Civil Servant Medical Benefit Scheme; DRG, Diagnosis Related Group; INR, International Normalized Ratio; SAVR, surgical aortic valve replacement; SHI, Social Health Insurance; UCS, Universal Coverage Scheme.

An additional scenario analyses estimated savings after accounting for mortality differences between European and Thai populations. In particular, the additive model applied Thai-specific mortality annualized rates based on the United Nations Population Division estimates and added the excess mortality associated with SAVR surgery for each age (deterministic model results listed in Appendix Table 15 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003). The results proved robust, and in some cases, the savings estimate associated with tissue SAVR valves increased relative to the base case. When expert opinion is relied on for the valuation of RVs in the Thai DRG, savings estimates remain very stable relative to the base case (Appendix Table 16 in Supplemental Materials found at https://dx.doi.org/10.1016/j.vhri.2022.06.003).

Discussion

One of the helpful outputs of the model is the identification of reoperation and anticoagulation monitoring costs as central drivers in the net costs (higher reoperation of tissue valves reduces savings, but lower ACM costs increase savings related to tissue valves). Although most of the sensitivity analyses suggest a plausible increase in savings associated with tissue valves (relative to base case results) as tissue valve performance improves, the breakeven results indicate that savings may diminish if ACM costs after a mechanical valve SAVR for patients are particularly low. Nevertheless, recent developments, such as the emergence of more expensive ACM medications, suggest the savings associated with ACM are more likely to increase over time if new, innovative medicines (novel oral anticoagulants or NOACs) are used after mechanical SAVR operations instead of warfarin. Payers in the Thai health system generally harbor a substantial share of healthcare costs for enrollees—but not always. In some cases, medical technologies will not be covered and the financial onus falls on the individuals patient if they decide to use and benefit from these innovative technologies. Enrollees frequently will remain in the same insurance payer, so these long-run savings will, in many cases, accrue to the original payer that covers the initial SAVR surgery. Conditional on opting for SAVR as the preferred treatment for AS patients, payers should consider reimbursement or extending insurance coverage for tissue valves rather than shift costs associated with novel valve technologies to patients. Reimbursement or coverage will reduce future health expenditures from the perspective of the Thai health insurers.

Our model focuses on reimbursement as a proxy for payer costs from insurer sources. To the extent additional payments covered by individuals or providers (physicians or hospitals) associated with the SAVR operations or subsequent clinical events related to SAVR treatment exist, these costs are excluded from our analysis. Financial savings are also just one pillar or determinant in deciding which technology is most appropriate for a particular patient, but Thai insurers should find it helpful to understand the long-run economic implications associated with tissue and mechanical valves used in SAVR. Our model relies on historical clinical data collected over decades, but technology has shifted (especially with respect to tissue valves). As such, the base case savings likely represent an underestimate of the actual insurer value, especially if lower reoperation rates from recent tissue valve technologies continue to hold over longer term. We also make relatively conservative assumptions. For example, bleeding probabilities for mechanical valves likely were underestimated in years 15 to 25. A "forward-looking" perspective might be better represented by the sensitivity analysis in which mortality and reoperation rates are adjusted downward—the net effect of these 2 factors generally leads to greater estimated savings.

Although previous literature related to this study has focused on either (1) the cost of sequelae[37-40] or (2) incidence of sequelae over time after either tissue or mechanical SAVR,[22,27,41-43] the US study by Nguyen et al,[23] which focused on overall long-run expected costs associated with tissue versus mechanical SAVR, is the most prominent study previously published that focuses on long-run costs. Both studies show a significant cost savings associated with the use of tissue SAVR valves in their "base case" models, but the relative size of the effect is lower in our Thai study because (1) prices of medical services are generally lower in Thailand than the United States, (2) the Thai costs focus mainly on government reimbursement only rather than total health system costs as in the US case, and (3) the relative prices for each of the sequelae and SAVR operation costs differ in Thailand in relation to the United States.

An important limitation of our analysis is the use of inputs from cohort studies in the absence of randomized controlled trials. As such, the findings are associations rather than causal evidence. Historical cohort studies can have limited capacity to risk adjust or address selection and current outcomes that may have evolved over time. Nevertheless, we believe that randomized controlled trials with sufficient power to detect long-run cost outcomes would not be feasible and that this study is a "next best" approach to help payers envision the value that likely accrues over time by using tissue rather than mechanical valves. In addition, because we use relative risks to "translate" incidence rates in a tissue SAVR cohort to a mechanical SAVR cohort, any limitations associated with appropriate estimation of tissue SAVR sequelae may bias the estimates in the mechanical SAVR cohort as well.

The models and sensitivity analyses accommodate Thai payer costs and Thai mortality data, but to the degree that there may be higher reoperation rates in Thai populations relative to European population based on minor physiological differences, savings may be lower. Further study is recommended, particularly on newer tissue and mechanical valves, to identify the degree to which these differences impact savings. Nevertheless, given that all the CIs for savings exceed $0 by a wide margin, we think it is likely that savings are still positive. With an increasing emphasis on lifelong management of patients with AS, the use of tissue valves also confers other benefits related to quality of life and retains the option to use less invasive surgical techniques, such as a transcatheter aortic valve replacement, should any subsequent aortic valve replacement procedures be required—such benefits are not accounted in this reimbursement analysis. Although we are careful to estimate reimbursements in the Thai system, forward-looking prospective cost analyses that measure actual costs (to insurers, patients and providers) in SAVR patients over time and account for clinical differences between patients within Thailand are recommended to add further robustness for future economic evaluations on this important clinical procedure. If clinical evidence continues to demonstrate improved patient outcomes with appropriate use of tissue SAVR, our study suggests that payers, providers, and the health system might increasingly benefit financially from the use of tissue valves.

Conclusion

From the perspectives of Thailand's 3 national health insurers, our simulation models show that long-run payer costs associated with tissue SAVR valves generally are less than with mechanical valves. The magnitude of the SAVR-related savings differs depending on the age of the patient at their initial SAVR operation and the Thai insurance source, but our base case estimates ranged from $2300 to $4500 for 25-year discounted cumulative savings. These results are robust to various sensitivity analyses and scenarios in which key inputs are adjusted—especially inputs surrounding mortality, reoperation, and anticoagulation monitoring.

Supplemental Materials

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