Cost of individual complications following coronary artery bypass grafting

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ABSTRACT

Objective: The financial implications of postoperative complications in cardiac surgery remain poorly understood. The purpose of this study was to define the cost of surgery without complications and demonstrate the incremental cost of each complication.

Methods: All patients undergoing isolated coronary artery bypass grafting (CABG) were evaluated (2006-2015) from a statewide Society of Thoracic Surgeons database collaborative (N = 36,588). Patients were stratified by presence of postoperative complications, including major morbidities as defined by the Society of Thoracic Surgeons (ie, prolonged ventilation, renal failure, reoperation, stroke, and deep sternal wound infection). Hierarchical modeling was used to identify the independent inflation-adjusted cost of each complication while controlling for hospital variation and time.

Results: The median age was 64 years, 74.3% were men, and average predicted risk of mortality was 1.9%. A total of 24,738 (67.7%) patients experienced no complications at an average cost of \$36,580. Each complication independently increases the cost of care and resulted in an exponential increase in cost. After accounting for incidence and incremental costs, institutions in our collaborative have spent an estimated \$59.1 million on prolonged ventilation, \$8.3 million on renal failure, \$7.6 million on reoperation, \$3.3 million on stroke, and \$256,000 on deep sternal wound infections over the past 10 years.

Conclusions: The average cost of CABG without complication was \$36,580. Each additional major complication resulted in an exponential increase in cost. Over the past 10 years, the total cost of complications after isolated CABG was \$78.6 million, emphasizing the importance of quality improvement projects to contain costs. (J Thorac Cardiovasc Surg 2018;155:875-82)

Complication-related expenditures over 10 years in the Virginia Cardiac Services Quality Initiative.

Central Message

Coronary artery bypass grafting without complications costs \$36,580 on average. Each additional major morbidity results in exponential cost increases with a 10-year total cost of \$78.6 million.

Perspective

Given the fiscal challenges expected with the bundled payment program for coronary artery bypass grafting, it is critical to understand the financial implications of postoperative complications in cardiac surgery. Understanding the costs of adverse events will help guide quality improvement projects, adapt to alternative payment models, and ultimately contain cost increases.

See Editorial Commentary page 883.

Given the growing emphasis on value-driven health care, research should evaluate both sides of this equation; that is, health care-related cost and clinical outcomes. Therefore, it is critical to understand the financial implications of postoperative complications after cardiac

surgery. Complications are the major driver of cost variability and are a key target for cost reduction.¹ Furthermore, it is critical to understand the cost of adverse events to estimate true costs and guide quality improvement projects. Knowing this information also allows for critical

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Supported by The National Heart, Lung, and Blood Institute of the National Institutes of Health (Award Nos. T32HL007849 and UM1HL088925). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Read at the 43rd Annual Meeting of the Western Thoracic Surgical Association, Colorado Springs, Colorado, June 21-24, 2017.

Received for publication May 17, 2017; revisions received July 17, 2017; accepted for publication Aug 11, 2017; available ahead of print Dec 14, 2017.

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0022-5223/\$36.00

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<https://doi.org/10.1016/j.jtcvs.2017.08.144>

Abbreviations and Acronyms

CABG	= coronary artery bypass grafting
CMS	= Centers for Medicare and Medicaid Services
IPPS	= Inpatient Prospective Payment System
LOS	= length of stay
STS	= Society of Thoracic Surgeons
VCSQI	= Virginia Cardiac Services Quality Initiative

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review of projects with accurate cost-effectiveness analyses.^{2,3} As we transition away from a fee-for-service model to a quality-based system, understanding these costs will be critical in building risk-adjusted payment models.⁴

Cardiac surgery has a unique set of complications that are major drivers in the cost of surgery.⁵ Brown and colleagues⁶ found the mean cost of coronary artery bypass grafting (CABG) amongst Medicare beneficiaries to be \$32,201 ± \$23,059 in 2008. In this same study, 13.64% of the study population experienced a postoperative complication resulting in increased costs and length of stay (LOS) of \$15,468 and 5.3 days, respectively. These costs continue to increase and are outpacing estimates of medical inflation by the Centers for Medicare and Medicaid Services (CMS) Inpatient Prospective Payment System (IPPS). Another study by Speir and colleagues⁵ specifically demonstrated isolated postoperative atrial fibrillation to increase the cost of CABG on average \$2574, whereas prolonged ventilation, renal failure, and deep sternal wound infection had the greatest increases in total cost. Other studies have shown isolated postoperative atrial fibrillation to be associated with an additional \$7000 to \$14,000 cost increase.⁷⁻¹⁰ The large cost of complications and variation in estimates has resulted in poorly defined costs that are unable to be accurately predicted with current cost models.¹¹⁻¹⁴

The purpose of this study is to analyze data from a statewide collaborative to define the cost of surgery without complications and demonstrate the incremental cost of each complication. These data may be used to identify and prioritize quality improvement initiatives that will improve patient care while providing cost-effective interventions.

MATERIALS AND METHODS

Patient Data

The Virginia Cardiac Services Quality Initiative (VCSQI) is composed of 18 hospitals and cardiac surgical practices in Virginia capturing 99% of adult cardiac surgery cases in the state. Data are collected using the Society of Thoracic Surgeons (STS) clinical data entry form to capture administrative, demographic, baseline clinical, operative, and 30-day outcome data. VCSQI clinical and cost data acquisition and matching has been described previously.^{15,16} Charges are captured by the International Classification of Diseases, ninth revision, based revenue codes and Uniform Billing-04/92 files are matched to the STS data, with a successful matching rate of 99%. These final hospital charges are then converted to estimate costs using cost-to-charge ratios submitted to CMS by each institution. Inflation estimates of the CMS IPPS were used to adjust cost to 2015 dollars to account for medical-specific inflation.

All patients undergoing isolated CABG (N = 36,588) in the VCSQI database from January 2006 through December 2015 were evaluated. Patients were excluded for missing cost data. STS definitions were used, including postoperative atrial fibrillation and major morbidity (renal failure, reoperation, stroke, deep sternal wound infection, and prolonged ventilation).¹⁷ The data were de-identified with removal of all Health Insurance Portability and Accountability Act patient identifiers. The study was granted exemption by the University of Virginia Institutional Review Board.

Statistical Analysis

Distributions of continuous variables were not normal so they were presented as median and interquartile range except cost, which was presented as mean ± standard deviation to more fully account for costs incurred. Categorical data were summarized as number and corresponding proportion. Nonparametric tests were used to compare categorical and continuous data for each of the preoperative variables stratified by incidence of an STS major morbidity. Additionally, mean costs were calculated with an incremental additive cost from surgery without complications. To ascertain the cost of each individual complication, hierarchical multivariate linear regression was used to estimate the contribution of each event to the total hospital cost. This was also performed for total hospital LOS and intensive care unit LOS. Each in-hospital postoperative event occurring with a frequency of at least 5% was included in the model as well as all STS major morbidities. Models included all complications of interest, and were adjusted for surgery without complications, hospital and year. Variation of inflation factors was used to assess collinearity of variables within the model. All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc, Cary, NC). Statistical significance was set at $\alpha < 0.05$. Incremental cost of major morbidities and change in cost over time were modeled in Prism 7 (GraphPad Software Inc, La Jolla, Calif) with calculation of goodness of fit.

RESULTS

Baseline Characteristics and Outcomes

Over the past decade, 36,588 patients underwent isolated CABG at the 18 centers in the Commonwealth of Virginia. The average age was 64 years, 74.3% were men, and mean STS predicted risk of mortality was 1.9% at 30 days. Patients experiencing STS major morbidities postoperatively were older, with significantly higher rates of medical comorbidities and underwent longer operations (Table 1). Additionally, over the past 10 years patients undergoing isolated CABG have had increasing risk profiles for both STS Predicted Risk of Mortality (slope [m] = 0.103; $P = .003$) and STS Predicted Risk of Morbidity and Mortality (slope [m] = 0.330; $P < .0001$) as demonstrated in Figure E1. Despite this

TABLE 1. Population characteristics

Characteristic	No major morbidity (n = 31,815)	Major morbidity (n = 4773)	P value
Preoperative			
Age (y)	64 ± 14	66 ± 15	<.0001
Sex (male)	23,574 (74.1)	3575 (74.8)	<.0001
Body mass index	28.7 ± 6.9	29.4 ± 8.0	<.0001
Diabetes	13,312 (41.8)	2382 (49.9)	<.0001
Hypertension	26,811 (84.3)	4222 (88.5)	<.0001
End-stage renal disease	680 (2.8)	246 (6.8)	<.0001
Ejection fraction (%)	55 ± 15	50 ± 25	<.0001
Number of diseased vessels			<.0001
1	1373 (4.3)	134 (2.8)	
2	6065 (19.1)	721 (15.1)	
≥ 3	24,295 (76.5)	3893 (81.8)	
Urgent status	18,156 (57.1)	2922 (61.2)	<.0001
Hematocrit	39 ± 6	37 ± 8	<.0001
Society of Thoracic Surgeons Predicted Risk of Morbidity and Mortality score (%)	10.2 ± 8.4	17.5 ± 18.5	<.0001
Society of Thoracic Surgeons Predicted Risk of Mortality score (%)	0.9 ± 1.2	1.9 ± 3.3	<.0001
Operative			
Cardiopulmonary bypass used	29,137 (91.6)	4460 (93.4)	<.0001
Cardiopulmonary bypass time (min)	90 ± 42	96.5 ± 47	<.0001
Both internal thoracic arteries used	979 (3.1)	83 (1.7)	<.0001
Left internal thoracic artery used	29,013 (91.3)	4174 (87.5)	<.0001
No internal thoracic artery used	1629 (5.1)	494 (10.4)	<.0001

Values are presented as median (interquartile range).

increasing risk, outcomes in this population were better than predicted with observed to expected ratios for major morbidity and mortality below 1.0 (Table 1). Of note, the rate of postoperative atrial fibrillation was 18.4% in this population (Table 2).

Influence of Major Morbidities

Incremental additive cost of each additional complication was calculated using surgery without complications as the baseline (Table 3). The cost of CABG without complications in this population was \$36,580 ± \$14,633. Mean cost for isolated atrial fibrillation includes patients with postoperative atrial fibrillation as their only postoperative

occurrence. The zero major morbidities group includes patients with in-hospital occurrences but no STS major morbidities. Each additional major morbidity experienced by patients incurred increase in total hospital cost (Figure 1). This curve was compared for goodness of fit between an exponential growth equation ($R^2 = 0.999$) and a linear equation ($R^2 = 0.942$) demonstrating each additional major morbidity is not additive, but instead exponentially increases cost. The exponential model demonstrated good fit with $\kappa = 0.548$ and a doubling every additional 1.2 major morbidities.

Rising Cost of Complications

Despite medical inflation adjustment using the CMS IPPS, cost of CABG has increased over the past decade ($P < .0001$). When stratified by patients with (slope, \$3984 ± \$709 per year) and without (slope, \$1360 ± \$127 per year) a STS major morbidity, we demonstrate the rate of increase in yearly mean cost is significantly higher in the group with complications (Figure 2) ($P = .002$). The linear regression for each model performed adequately (no major morbidity $R^2 = 0.94$ and major morbidity $R^2 = 0.80$).

Incremental Cost of Complications

Results of the hierarchical model define costs for each complication (Table 3). The model performed well, with

TABLE 2. Outcomes (N = 36,588)

Postoperative	Result
Atrial fibrillation	6745 (18.4)
Prolonged ventilation	3281 (9.0)
Reoperation	1189 (3.3)
Renal failure	963 (2.6)
Stroke	435 (1.2)
Deep sternal wound infection	27 (0.1)
Any major morbidity	4628 (12.7)
30-d mortality	230 (0.6)

Values are presented as n (%).

TABLE 3. Incremental cost of major morbidities after coronary artery bypass surgery

Population	Patients (n [%])	Mean $\pm$ standard deviation	Difference
Surgery without any complication	24,738 (67.7)	36,580 $\pm$ 14,633	—
Isolated postoperative atrial fibrillation	5345 (14.6)	42,363 $\pm$ 18,354	+5783
0 STS major morbidities	31,960 (87.2)	38,345 $\pm$ 16,412	+1675
1 STS major morbidity	3584 (9.8)	64,542 $\pm$ 39,456	+27,872
2 STS major morbidities	839 (2.3)	111,239 $\pm$ 76,177	+74,569
3+ STS major morbidities	205 (0.6)	194,043 $\pm$ 127,518	+157,463

STS, Society of Thoracic Surgeons.

an R^2 value of 0.724 (Table 4). Based on these estimates and the incidence rate of each major morbidity, the overall costs of each complication over the past 10 years in the Commonwealth of Virginia were calculated (Figure 3). Cardiac surgery centers in the VCSQI collaborative have spent more than \$78.6 million on complications with prolonged ventilation being the highest at \$59.1 million due to the high incidence. To further evaluate the influence of complications on resource utilization, we demonstrate that each complication has a significant and predictable effect on hospital LOS (Table E1) ($R^2 = 0.410$). Likewise, we see a similar effect for intensive care unit LOS (Table E2) ($R^2 = 0.346$).

DISCUSSION

The cost of CABG is highly variable and continues to rise, outpacing medical inflation. These increases are significantly influenced by postoperative complications, the cost of which is growing at an even more rapid rate. The current cost of CABG without complications is \$36,580 in 2015 dollars. The cost of each major morbidity accrued is not additive, but instead found to increase total cost exponentially.

FIGURE 1. Incremental cost of major morbidities after coronary artery bypass surgery. Each additional major morbidity experienced by patients incurs a major increase in total hospital cost. This curve was compared for goodness of fit between an exponential growth equation ($R^2 = 0.999$) and a linear equation ($R^2 = 0.942$). The exponential model demonstrated good fit with $\kappa = 0.548$ and a doubling with every additional 1.2 major morbidities.

This study also calculates the independent cost of each common complication after cardiac surgery. Finally, when considering the incidence of each event, we demonstrate that prolonged ventilation had the highest cumulative cost over the past decade in the Commonwealth of Virginia.

The estimates for complication-free CABG surgery continue to rise, over and above medical inflation, which is adjusted for using CMS IPPS estimates. Kilic and colleagues¹ in 2014 reported that complications after cardiac surgery are the primary driver of cost variation. Our data further support this claim. We demonstrate a significantly higher rate of increase in patients with STS major morbidities compared with costs in patients not experiencing a STS major morbidity after surgery. The increasing risk profiles of patients undergoing CABG continue to make case more challenging with fewer low risk operations.^{18,19} Given the complexity of cases and the growing burden of comorbid disease, these complications will become more difficult to prevent despite being a driving force behind expanding costs. Therefore, understanding these expenses and being able to accurately predict them will be critical

FIGURE 2. Rate of cost increase over time. Despite medical inflation adjustment using the Center for Medicare and Medicaid Services Inpatient Prospective Payment System, cost of coronary artery bypass grafting has continued to increase over the past decade ($P < .0001$). Patients were stratified as having a Society of Thoracic Surgeons major morbidity (orange line, slope = 3984 $\pm$ 708.8) or not (blue line, slope = 1360 $\pm$ 127) ($P = .002$). The linear regression for each model performed adequately (no major morbidity $R^2 = 0.94$ and major morbidity $R^2 = 0.80$).

TABLE 4. Independent cost effects of complications after coronary artery bypass grafting

Complication	Estimate (\$)	95% Confidence interval	P value
Blood transfusion	+6763	6195-7331	<.0001
Postoperative atrial fibrillation	+5673	4760-6586	<.0001
Prolonged ventilation (>24 h)	+33,840	32,826-34,855	<.0001
Reoperation	+35,239	33,772-36,706	<.0001
Stroke	+18,423	16,147-20,699	<.0001
Renal failure	+33,847	32,269-35,424	<.0001
Deep sternal wound infection	+19,835	10,937-28,733	<.0001
Operative mortality	+13,474	10,403-16,545	<.0001

in developing payment models to appropriately reimburse hospital systems providing care to these complex patients with high risk of complications.

Prior work has identified the incremental costs associated with certain complications.⁵ Our work builds on this by examining the interaction between complications, which suggests that accumulation of multiple major morbidities increase cost exponentially. This highlights the difficulty in predicting costs. Patients who develop a single complication are at increased risk for a subsequent complication, and these additional costs should be modeled on a logarithmic order. Although the STS risk predictor tool does an outstanding job of predicting clinical outcomes, these models do not accurately risk adjust for cost.^{20,21} Our group has recently demonstrated that cost models do not adequately account for patients experiencing complications after surgery, as modeled in the CABG bundled payments using DRG definitions.¹⁴ Therefore, it

is critical for large datasets like the VCSQI to regularly update these estimates for cost modeling.

In the era of quality improvement, cardiac surgery programs are bombarded with various protocols and initiatives to improve the overall care of patients. However, using the value framework, these initiatives should be evaluated on the basis of cost-effectiveness using the specific cost estimates that have been derived via this study. We have demonstrated that prolonged ventilation incurs the highest expenditures in Virginia. Given the high incidence, this equates to a price tag of \$59.1 million attributable over the past decade. Given this financial burden, our quality collaborative has focused on initiatives that will reduce this common complication. Similarly, blood transfusions have a significant financial burden given the high incidence of administration. Our group has recently demonstrated the use of rotational thromboelastometry to decrease blood transfusion.²² Additionally, several institutions have moved to prophylactic amiodarone protocols to reduce the incidence of postoperative atrial fibrillation. With the use of cost estimates derived from large collaborative datasets, these quality improvement projects can be rigorously and quantitatively evaluated using cost-effectiveness methods to ensure value is provided.

This study is limited by its retrospective nature with inherent selection bias and precludes demonstration of causality. Furthermore, the VCSQI uses cost-to-charge ratios reported to CMS each year to estimate cost. Hierarchical modeling was used to adjust for hospital-level variation as well as yearly variation during the study period; however, we are unable to adjust for unknown factors that may contribute bias to the study.

CONCLUSIONS

The increasing cost of CABG is outpacing medical-specific inflation and is driven primarily by postoperative complications. Whereas each complication has incremental costs directly attributable to its treatment, each additional complication increases total hospital cost exponentially. The significant variations in total hospital costs make payment models susceptible to significant error. Accurate estimates for costs attributable to specific complications will be critical as we move toward value-based health care models.

Conflict of Interest Statement

A.S. is a consultant on the Medtronic Cardiac Surgery Advisory Board and G.A. is a consultant for Abbott, Edwards, and Medtronic, and has been a speaker for Atricure within the past 3 years but not in the past year. All other authors have nothing to disclose with regard to commercial support.

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FIGURE 3. Complication-related expenditures over 10 years in Virginia. Cardiac surgery centers in the Virginia Cardiac Services Quality Initiative collaborative have spent more than \$78.6 million on complications with prolonged ventilation being the highest at \$59.1 million due to the high incidence.

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Key Words: cardiac surgery, cost, complications, incremental cost

Discussion

Moderators: Nahush A. Mokadam

John D. Mitchell

Moderator. Good morning everybody. We'll start off this session with paper number 4, "Cost of Individual Complications Following Coronary Artery Bypass Grafting," presented by Dr Mehaffey from UVA, and colleagues.

James Mehaffey. Thank you for the opportunity to present our work. We have no disclosures. So, it's critical to understand the financial implications of postoperative complications in cardiac surgery. It's important to be able to evaluate our quality improvement initiatives, it's important to be able to define value in healthcare, and it will provide a framework for future bundled payment programs. The purpose of this study was to define the cost of coronary artery bypass grafting with no complications, and demonstrate individual and incremental cost of complications in a statewide data set. We hypothesized that complications after CABG are associated with specific and definable costs and each additional complication results in exponential increase in cost. We used the Virginia Cardiac Services Quality Initiative, which is a consortium of the 19 cardiac institutions in the state of Virginia who pool their society of thoracic surgeons' data. Additionally, the database includes UB-04 billing data and institution-specific cost:charge ratio, which allows a calculation of estimated true cost. We evaluated all patients undergoing isolated CABG over a ten-year period from 2006 through 2015. This was a total of 36,588 cases. We evaluated each of the Society of Thoracic Surgery major morbidities defined as prolonged ventilation greater than 24 hours, reoperation, renal failure, stroke, and deep sternal wound infection. Additionally, we looked at minor complications, including postoperative atrial fibrillation as well as blood transfusion. We then used hierarchical linear regression

modeling with complications as covariates and accounted for random effects of institution level variability and year.

So here was our standard isolated CABG population, 36,000 patients, predicted risk of mortality just under 2%, a pretty standard population. When we evaluated the outcomes, we see that patients in our collaborative did quite well with postoperative atrial fibrillation rates of 18.4% and 30-day mortality less than 1%. When we look at observed:expected ratios for both major morbidity or mortality as well as 30-day mortality, we see that the collaborative as a whole performed better than expected and had an O:E ratio less than 1.0. We next evaluated the inflation-adjusted costs of coronary artery bypass for this patient population. As you can see here, patients with no complications, meaning they do not experience an STS major morbidity or any of the minor complications have an average total hospital cost of \$36,500. Now the subset of patients who experienced a minor complication but did not experience a major morbidity had an average increase of about \$2000 in their total hospital cost. However, the population of patients experiencing one or more major morbidities demonstrated a significant and dramatic increase in total hospital costs, and this demonstrated an exponential relationship as demonstrated here in the figure with each additional major morbidity. We next looked at the cost of coronary artery bypass over time, and for this again we used inflation-adjusted cost, adjusted by the Center for Medicare and Medicaid Services, medical specific inflation adjustment, so the blue line at the bottom demonstrates the total hospital cost of all patients undergoing CABG who did not experience one of the STS major morbidities.

As you can see here, despite adjustment for inflation, the cost increased by about \$1300 a year. However, in the orange line above, this demonstrates the average hospital cost of the patients experiencing one or more major morbidities, and you can see here once again after adjustment for inflation, these patients had a yearly increase of almost \$4000 in total hospital costs. We next used hierarchical linear regression to identify attributable cost for each of these major morbidities as well as minor complications to the total hospital cost of the patient. As you can see here in our collaborative, some of the most costly morbidities included reoperation, renal failure, and prolonged ventilation. However, even the minor complications contributed significantly to the model, both blood transfusion and postoperative AFib contributing about \$6000 in total hospital cost to patients experiencing this complication. However, this doesn't tell the whole story, because while we can identify the costs associated with each individual complication, we must look at this in the framework of considering the incidence of that complication. So next we looked at the total ten-year cost within the collaborative of each of these major morbidities. We did this by multiplying the incidence of the complication by the incremental cost of that

complication, prolonged ventilation and atrial fibrillation were the most costly complications. Limitations of this study include its retrospective nature and the inability to evaluate variables that are not included in the database. In conclusion, additional complications increase total hospital costs and the cost of CABG is outpacing medical specific inflation, and is driven primarily by postoperative complications. Furthermore, specific complications have identifiable cost that may be used for risk adjustment and reimbursement models. However, total expenditure is based on cost and incidence of complication, therefore accurate cost estimation should be used to guide research and quality improvement allocation.

Participant. Congratulations, so really nice and ____ [tape blank]. I have a few questions, I have 4 questions for you. First related to methodology ____ [tape blank] I noted that the ____ [tape blank] for all the complications ____ [tape blank] but you know, I think comorbidities ____ [tape blank] may affect the population ____ [tape blank] for example patients with diabetes, who goes back to ____ [tape blank].

Participant. What about ... did you consider at all including comorbid variables ____ [tape blank] in your model that might help us ____ [tape blank].

James Mehaffey. Yeah I think that's an excellent question and what you're hitting on is essentially what Medicare is doing right now, their goal is to build a model to predict how much a CABG patient is going to cost to take care of. The problem with this goal is that while predicting average cost is possible with statistical modeling, there are significant cost outliers. The proposed bundled payments shifts this financial risk to the institutions. The other problem with models is they are based on preoperative characteristics and I think the answer is not just comorbidities, it's socioeconomic factors, payer status, it's how far they are traveling for their operation and where they come from and what kind of care infrastructure they have when they go back there.

Participant. Certainly, I 100% agree that it's part of a model that predicts what the cost will ____ [tape blank] and I think that is one of the things that our outcomes group is working on and we definitely don't have the answer to that. This study is certainly not directly trying to build a cost model for reimbursement, but to your point, ____ [tape blank] % will include patient level medical factors, as well as patient level socioeconomic ____ [tape blank] crisis of our generation ____ [tape blank].

Participant. ____ [tape blank] % of the ____ [tape blank] differences in the conversation ____ [tape blank].

James Mehaffey. Yes, that's an excellent question and the subset analysis has not ____ [tape blank] relatively low rates of ____ [tape blank] very early study period. I think adjustment for ____ [tape blank] look at further patient outcome ____ [tape blank].

Participant. One other thing in your slide _____ [tape blank] didn't end up in your overall analysis. I wonder what the overall cost of the single blood transfusion _____ [tape blank] that's one of the things that _____ [tape blank].

James Mehaffey. Certainly, I think that's a really good question, and I think that it's actually two-fold, it's not just how much the bag of red blood cells costs, and what this analysis got at is for a patient who got a blood transfusion how does that effect the cost overall. Clearly the bag of blood doesn't cost \$6,000 it's more looking at the patient who's getting a blood transfusion has so many other issues going on and we identified that cost. You look back in the last decade and institutions in our collaborative spend over \$60 million on prolonged ventilation and \$30 million on Afib and those are the center of our quality improvement initiatives. You have to find and identify one thing that you're going to tackle first and one way to decide if what has the largest financial burden.

Richard Shemin. This is very useful data from all the cardiac surgery centers in Virginia. You have quantified the cost of complications after CABG surgery. How will you specifically use the data for bundled negotiation?

James Mehaffey. Certainly and I'm actually going to tackle your second

question first. Postoperative AFib as you mentioned has been one of our low performance outliers and just from the beginning of the decade that we looked at, we had rates over 25% and in the last couple of years it's been low, 15 or 16%. I think we are moving the needle on this bar, and making a meaningful impact. Your first question...

Richard Shemin. How much institutional variability do you measure among the participating centers?

James Mehaffey. Yes, variability is unbelievable and I think that's one of the biggest issues with creating a cost model. One of our recent studies show that if you implemented the proposed CABG bundle, a difference in how that would have done if the last 5 years were the proposed next 5 years is terrifying. There are several hospitals in our collaborative that would owe Medicare a couple million dollars just because of the cost of variability. With the shifting of financial risks to the hospitals this variability makes me wonder how some institutions can survive.

Richard Shemin. My final quick comment returns to the complexity of these efforts to capture patient viability, best practice and cost containment so the result of bundled methodology does not bankrupt our hospitals.

James Mehaffey. Certainly, and I think that's an excellent question and something Dr Rich is actively working to get all payer charges for patients post acute care.

FIGURE E1. Risk profiles over 10 years in Virginia. Yearly average Society of Thoracic Surgeons Predicted Risk of Mortality (*PROM*) and Society of Thoracic Surgeons Predicted Risk of Mortality and Morbidity (*PROMM*) scores for all cardiac surgery centers in the Virginia Cardiac Services Quality Initiative collaborative are increasing yearly over the past decade.

TABLE E2. Independent intensive care unit length of stay effects of complications after coronary artery bypass grafting

Complication	95% Confidence		
	Estimate (h)	interval	P value
Blood transfusion	24.73	23.63-25.84	<.0001
Postoperative atrial fibrillation	33.73	31.94-35.53	<.0001
Prolonged ventilation (>24 h)	152.32	150.33-154.31	<.0001
Reoperation	105.28	102.39-108.16	<.0001
Stroke	102.72	98.22-107.22	<.0001
Renal failure	127.90	124.80-131.00	<.0001
Deep sternal wound infection	19.61	2.30-36.93	.2572
Operative mortality	43.52	37.43-49.61	<.0001

TABLE E1. Independent length of stay effects of complications after coronary artery bypass grafting

Complication	95% Confidence		
	Estimate (d)	interval	P value
Blood transfusion	1.76	1.71-1.82	<.0001
Postoperative atrial fibrillation	1.42	1.33-1.51	<.0001
Prolonged ventilation (>24 h)	6.86	6.76-6.97	<.0001
Reoperation	7.20	7.05-7.35	<.0001
Stroke	5.95	5.72-6.18	<.0001
Renal failure	7.74	7.58-7.90	<.0001
Deep sternal wound infection	2.96	2.06-3.86	.001
Operative mortality	2.76	2.4-3.07	<.0001