Original Research

State Perinatal Quality Collaborative for Reducing Severe Maternal Morbidity From Hemorrhage

A Cost-Effectiveness Analysis

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OBJECTIVE: To evaluate the cost effectiveness of California's statewide perinatal quality collaborative for reducing severe maternal morbidity (SMM) from hemorrhage.

METHODS: A decision-analytic model using open source software (Amua 0.30) compared outcomes and costs within a simulated cohort of 480,000 births to assess the annual effect in the state of California. Our model captures both the short-term costs and outcomes that surround labor and delivery and long-term effects over a person's remaining lifetime. Previous studies that evaluated the effectiveness of the CMQCC's (California Maternal Quality Care Collaborative) statewide perinatal quality collaborative initiative—reduction of hemorrhage-related SMM by increasing recognition, measurement, and timely response to postpartum hemorrhage—provided estimates of intervention effectiveness. Primary cost data received from select hospitals within the study allowed for the estimation of collaborative costs, with all other model inputs derived from literature. Costs were inflated to 2021 dollars with a cost-effectiveness threshold of $100,000 per quality-adjusted life-year (QALY) gained. Various sensitivity analyses were performed including one-way, scenario-based, and probabilistic sensitivity (Monte Carlo) analysis.

RESULTS: The collaborative was cost effective, exhibiting strong dominance when compared with the baseline or standard of care. In a theoretical cohort of 480,000 births, collaborative implementation added 182 QALYs (0.000379/birth) by averting 913 cases of SMM, 28 emergency hysterectomies, and one maternal mortality. Additionally, it saved $9 million ($17.78/birth) due to averted SMM costs. Although sensitivity analyses across parameter uncertainty ranges provided cases where the intervention was not cost saving, it remained cost effective throughout all analyses. Additionally, scenario-based sensitivity analysis found the intervention cost effective regardless of birth volume and implementation costs.

CONCLUSION: California's statewide perinatal quality collaborative initiative to reduce SMM from hemorrhage was cost effective—representing an inexpensive quality-improvement initiative that reduces the incidence of maternal morbidity and mortality, and potentially provides cost savings to the majority of birthing hospitals.

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Pregnancy-related maternal deaths in the United States have increased from 7.2 per 100,000 live births to 16.9 per 100,000 live births over the past 20 years, making the United States the only country in the Organization for Economic Cooperation and Development with rising rates of maternal mortality.[1] Postpartum hemorrhage (PPH), is the cause of 11% of maternal deaths.[1] Clinical signs of PPH, such as an elevated heart rate or decrease in blood pressure, are often recognized only after people have lost nearly 25% of their blood volume after delivery.[2] Further, blood loss puts people at risk for severe maternal morbidity (SMM), including ischemic disease leading to complications such as myocardial infarction, renal failure, shock, emergency hysterectomy, and death.[2] Collectively, these outcomes, as well as treatments given in response to PPH (eg, blood transfusion), comprise SMM, which increased significantly (190% increase) between 1999 and 2014.[3] Recognizing and treating PPH can reduce SMM and mortality.

To reduce rates of SMM from PPH at a system level,[4] the CMQCC (California Maternal Quality Care Collaborative), developed a PPH toolkit and corresponding quality-improvement initiative to increase recognition, measurement, and timely response to PPH. The CMQCC comprehensive initiative to accomplish the goal of reduction of SMM from PPH involves a multidomain systems implementation (Table 1) within a statewide collaborative.[5] Across the three domains–readiness, recognition and prevention, and response–this initiative bundled 18 specific components comprising of best practices, educational tools, sample protocols, policies, and other implementation aides. In 2017, the CMQCC demonstrated a significant reduction in PPH-related SMM in hospitals throughout California when they participated in the collaborative's initiative compared with comparative hospitals in California.[5]

Our aim was to evaluate the cost effectiveness of this initiative (referred to as the "PPH–SMM reduction initiative") across a mix of hospital types and sizes representative of the those found throughout the state of California. This approach allowed for incorporation of the large variance in implementation costs and challenges hospitals of differing sizes face when deciding whether to adopt quality-improvement initiatives.

METHODS

We created a cost-effectiveness model using open-source software (Amua 0.30)[6] to simulate a cohort of 480,000 births in the state of California. A decision tree and Markov models capture both the short-term outcomes surrounding labor and delivery and long-term effects over a person's remaining lifetime. The study evaluating the effectiveness of implementing the CMQCC's PPH–SMM reduction initiative provided estimates of intervention effectiveness (see Appendix 1, available online at http://links.lww.com/AOG/D2). Within this study, 74 hospitals that participated in the PPH–SMM reduction initiative reduced the rate of PPH-related SMM by 14.2%, compared with 47 hospitals that did not participate.[5] Primary cost data received from select hospitals within the study allowed for the estimation of intervention costs. Institutional review board review and approval was not required because our study was an economic analysis of an evaluative study and was not considered human subjects research.

Our theoretical cohort of 480,000 births was based on the 10-year average annual number of births in the state of California[7]–following cohorts of people giving birth at one of two types of hospitals: 1) a hospital participating in the PPH–SMM reduction initiative or 2) a hospital that did not (Fig. 1). In this time period (before the reVITALize recommendation of more than 1,000 mL for all births), the definition of PPH used in California hospitals was estimated blood loss of more than 500 mL at vaginal delivery and more than 1,000 mL at cesarean delivery. Because there was variation in both the ability to accurately quantify the blood loss and the PPH definition used, SMM following PPH was the focus of the collaborative and of this study. This model emulates the natural course of a person's labor and delivery with most people experiencing an uncomplicated vaginal birth regardless of which type of hospital they deliver in. Likewise, although some will develop PPH, others will experience morbidity and mortality from causes unrelated to PPH. The model tracks the occurrence of PPH with a focus on morbidity, mortality, and other long-term consequences. Although PPH is thought to increase the risk of numerous SMM outcomes, our model conservatively included only outcomes conclusively shown to have causal links to PPH: blood transfusion, emergency hysterectomy, and maternal mortality.[8] We assumed all PPH that resulted in SMM required at least one blood transfusion. Table 2 lists all model probabilities.

We used a risk of PPH of 5.9 per 100 births for our base case analyses using an estimated range of 4.2 per 100 births to 6.7 per 100 births.[5] This risk rate came directly from the CMQCC's data published in Main et al's 2017 study. We estimated maternal deaths related to PPH as 1.056 per 100,000 births by converting the estimated proportion of maternal deaths related to PPH (11%)[9] and the risk of maternal mortality in California (9.6/100,000 births).[10] We used a risk of PPH-related SMM as 1.34 per 100 births for our base case analyses.[5] This risk was based on combining the PPH risk and the proportion of SMM-related PPH (22.8%).[5] We incorporated all SMM and SMM by blood transfusion only as short-term outcomes to provide more accurate cost estimates for

Table 1. California Partnership for Maternal Safety Collaborative Structure Measures (N=17) Safety Bundle Elements (Dates Established or Completed Were Reported)

Readiness Domain	Recognition and Prevention Domain	Response Domain
Hemorrhage cart including instruction cards for intrauterine balloons and compression stitches	Assessment of hemorrhage risk (prenatal, admission, and other) (policy with time frames, mechanism for documentation)	Use of unit-standard, stage-based obstetrics hemorrhage emergency management plan with checklists
STAT access to hemorrhage medications (kit or equivalent)	Measurement of cumulative blood loss (formal and as quantitative as possible)	Support program for patients, families, and staff for all significant obstetric hemorrhages
Hemorrhage response team established (anesthesia, blood bank, advanced gynecological surgery, and other services)	Active management of third stage of labor (department-wide protocol for oxytocin at birth)	Reporting and systems learning domain
Massive transfusion protocols established		Establish culture of huddles to plan for high-risk patients
Emergency release protocol established for O-negative and uncross-matched units of RBC		Post event debriefing to quickly assess what went well and what could have been improved (agreed upon leader, time frame, with documentation)
Protocol for those who refuse blood products		Multidisciplinary reviews of all serious hemorrhages for system issues
Unit education to protocols		Monitor outcomes and progress in perinatal QI committee
Regular unit-based drills with debriefs for obstetric hemorrhage		

QI, quality improvement; RBC, red blood cells; STAT, immediate.

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hospitals avoiding PPH. By SMM definition, we assumed all PPH-related SMM required a blood transfusion.[3] Finally, we estimated the risk of PPH-related emergency hysterectomy as 1.83 per 1,000 births for our base case analyses.[11] This risk was based on combining the PPH risk and the risk of PPH-related emergency hysterectomies (3.1/100 PPH cases).[12–14]

The model distinctly estimated PPH-related emergency hysterectomy because it causes long lasting reduction in health-related quality of life. The physical and emotional recovery in the immediate postpartum period and the unexpected infertility across a lifetime leads to a decrease in quality-adjusted life-years (QALYs). Because the analysis is incremental, the model incorporated a simplifying assumption that the risk of hysterectomy for those people not experiencing PPH was zero.[12,13,15]

We assumed a health care perspective, meaning costs included current and future medical costs borne by third-party payers and out-of-pocket patient costs related to PPH as well as hospital costs related to the intervention (implementation and maintenance for participating in the PPH–SMM reduction initiative, such as supplies, equipment, training hours). All costs were inflated to 2021 using a combination of the Personal Health Care Expenditure deflator and the Personal Consumption Expenditure in accordance with the recommendations from the Second Panel on Cost Effectiveness in Health and Medicine.[16,17] We used $15.90 as the per birth cost of the PPH–SMM reduction initiative through structured interviews with hospitals in the collaborative. Interviews were conducted with nurses in managerial positions who implemented or maintained the PPH–SMM reduction initiative using the 18 components of the CMQCC's California Partnership for Maternal Safety collaborative structure[5] (see Appendix 1, http://links.lww.com/AOG/D2).

We extracted costs of normal birth and severe maternal morbidities from Phibbs et al[11] (2019, 2022) primary data used in previous published studies on maternal- and child-related hospital costs throughout California.[11,14] These data matched hospital discharge summaries and readmissions with birth certificates of recorded hospital births in nonfederal hospitals throughout California between 2009 and 2011 within the postnatal period.[14] Within these matched files, maternal and neonatal costs of "normal birth," and maternal and neonatal costs associated with SMM were collected and separated for individual analyses. Previous published literature using the same data set found significantly higher infant costs on average

Table 2. Model Parameters

Parameter	Base Case Point Estimate	Range Considered in Sensitivity Analysis	Reference(s)
Absolute reduction in PPH-related SMM risk from PPH–SMM reduction initiative	0.142	0.088–0.22	5
Probabilities			
PPH	0.059	0.029–0.067	5,24
SMM			
PPH-related SMM	0.0134	0.0096–0.0192	5
PPH-related emergency hysterectomy	0.00183	0.00063–0.00362	12–14
Maternal mortality			
Total maternal mortality	0.000096	0.000096–0.000026	10,25,26
PPH-related maternal mortality*	0.000011	0.000011–0.0000101	3,9
Utilities			
Emergency hysterectomy and related sequelae	0.82	0.61–0.88	8,18,19
Costs ($)			
Intervention (per birth)	15.90	6.31–39.27	Structured interviews
Normal birth (per birth)	8,812	57,800–19,549	14
PPH (per birth)†	0		
SMM, transfusion only (per birth)	23,264	18,084–38,135	11,14
SMM, other (per birth)	34,414	22,542–36,467	11,14

PPH, postpartum hemorrhage; SMM, severe maternal morbidity.
* Based on proportion of PPH-related total maternal mortality (11.0–11.2%).
† Costs assumed to reside within "Costs—Normal birth."

associated with their mother experiencing SMM than infants whose mothers did not.[11] Costs of normal birth included all associated neonatal and maternal costs (hospital and health care professional) within the postnatal period (42 days). Costs of SMM included all associated neonatal and maternal costs within a normal birth and the incremental neonatal and maternal costs associated with maternal SMM.[11]

In following the recommendations from the Second Panel on Cost Effectiveness in Health and Medicine, we reported both lifetime outcomes and those that capture the majority of meaningful differences, which for PPH is assumed to be during the postnatal period of up to 42 days after birth.[16] Our model incorporated two long-term outcomes from PPH: emergency hysterectomy and maternal mortality.[8] To do so, we tracked the loss in quality-adjusted life expectancy from mortality or a hysterectomy relative to the quality-adjusted life expectancy for an otherwise similar person who did not experience

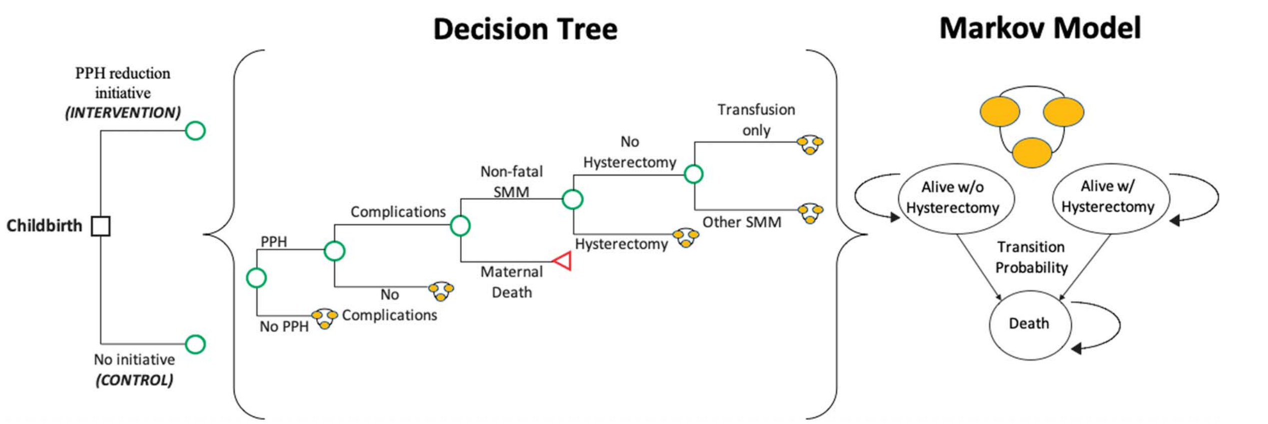

Fig. 1. Decision tree with Markov model. PPH, postpartum hemorrhage; SMM, severe maternal morbidity.
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one of these outcomes. Given their short duration, for other SMMs, we presume eventual recovery and negligible effect to QALYs over the time horizon of the entire lifespan.[8] As a result, we assumed no loss of quality of life in the model for other types of SMM.

Postpartum hemorrhage can lead to adverse outcomes that necessitate an emergency hysterectomy. Loss of fertility among other consequences of emergency hysterectomy can, in turn, reduce quality of life over the remaining lifetime. Prior studies found hysterectomy and subsequent infertility (quality of life weight 0.82 [range 0.61–0.82]) to have the largest effect on quality of life for nonfatal outcomes.[18,19]

We assessed the value of the PPH–SMM reduction initiative using incremental cost-effectiveness ratios, or the increase in cost for each QALY gained compared with the control group.[16] We discounted costs and effects in subsequent years at 3% per year, as recommended by the Second Panel on Cost Effectiveness in Health and Medicine.[16] Cost effectiveness was assessed at the willingness-to-pay (WTP) threshold of $100,000 per QALY gained.

To assess the robustness of the results, we performed the following sensitivity analyses: one-way, break-even, scenario-based, and probabilistic sensitivity analysis. Our one-way sensitivity analyses examined all parameters independently to evaluate the robustness of our results along each variable's uncertainty range. In break-even analysis, we reassessed the optimal strategy under a WTP of $0 per QALY gained or cost-savings threshold. Our scenario-based analyses first examined the relationships between hospital volume and implementation cost, and between hospital volume and intervention effectiveness. We conducted a probabilistic sensitivity analysis by fitting distributions for all parameters and allowing for all parameter values to vary simultaneously across their given distribution–recording the results of our analyses over 100,000 samples from these distributions (see Appendix 1, http://links.lww.com/AOG/D2). These distributions were beta distributions for all probabilities and utilities (where a=sample size* mean and b=sample size* 1-mean) and gamma distributions for all costs (where θ is estimated by variance/mean, $\beta=1/\theta$ and k is estimated as mean^2/variance or mean/θ).

RESULTS

For the 480,000 hypothetical annual births in California in our simulated cohort, 28,320 people experienced PPH. If the PPH–SMM reduction initiatives were not implemented, they experienced worse outcomes and higher costs compared with implementation of the toolkit.

With PPH–SMM reduction initiative implementation, people in the cohort experienced 5,518 total SMM events, 172 emergency hysterectomies, and eight maternal mortalities. In comparison, without PPH–SMM reduction initiative implementation, they experienced an additional 913 SMM events, 28 emergency hysterectomies, and one additional maternal mortality. These differences in outcomes led to a difference in 182 QALYs (discounted over a lifetime horizon) between PPH–SMM reduction initiative implementation and non-PPH–SMM reduction initiative implementation (12,432,035 vs 12,431,853). Eighty percent of the QALY gains were driven by averted emergency hysterectomies, with one averted maternal death making up the remaining 20% difference.

With PPH–SMM reduction initiative implementation, costs averaged $9,031 per birth, with a total annual cost over the entire cohort of $4.335 billion. Without implementation, costs averaged $9,049 per birth and totaled $4.344 billion. Lower costs ($9 million less) were due to averted SMM costs.

Implementing the PPH–SMM reduction initiative reduced the probability of complications from PPH and their sequelae including emergency hysterectomy, resulting in a longer quality-adjusted life expectancy. Likewise, even with the costs of delivering the intervention, these averted outcomes result in lower lifetime costs. Without PPH–SMM reduction initiative implementation, people experiencing PPH cost an additional $571 ($12,832 vs $12,261) and resulted in 0.006 less QALYs (25.861 vs 25.867) compared with those experiencing PPH with PPH–SMM reduction initiative implementation.

Overall, the PPH–SMM reduction initiative exhibited strong dominance compared with the baseline, adding 0.000379 QALYs per birth while requiring $17.78 less per birth on average (Table 3).

In one-way sensitivity analyses across the ranges for all probabilities, costs, and utilities, implementing the PPH–SMM reduction initiative remained the preferred strategy at a WTP threshold of $100,000 per QALY.

In a break-even or threshold analysis, each parameter range was once again considered, but this time with the objective to identify the strategy that produced the lowest net costs without considering a WTP threshold for utility. We found one parameter, the cost of implementing the PPH–SMM reduction initiative, sensitive along its range. When the cost was greater than $33.68 per birth, implementing the PPH–SMM reduction initiative was no longer cost saving when compared with the control. One-way break-even analyses for all other parameters did not change the conclusion that implementing the PPH–SMM reduction initiative was cost-saving.

Table 3. Strategy Comparison: Costs and Quality-Adjusted Life-Years (Per Birth)

Strategy	Cost ($)	Incremental Cost ($)	QALYs	Incremental QALYs	Strategy Comparison
No PPH–SMM reduction initiative implementation	9,049.23	—	25.89992	—	—
PPH–SMM reduction initiative implementation	9,031.45	17.78	25.900267	0.000379	Strongly dominant

QALY, quality-adjusted life-year; PPH, postpartum hemorrhage; SMM, severe maternal morbidity.

In scenario-based analysis we examined the relationship between birth volume and per-birth implementation cost within the collaborative hospitals we studied. Implementing the PPH–SMM reduction initiative was cost saving for hospitals that have volumes of 900 births or more and cost effective at a WTP threshold of $100,000 per QALY gained across the entire range considered. Assuming implementation costs were twice those predicted, the intervention would be cost saving for those hospitals with at least 2,600 births per year and cost effective at hospitals with at least 850 births per year (Fig. 2).

Because QALY gains were modeled based on average risks of SMM in the absence of the PPH–SMM reduction initiative, we further examined the effectiveness of implementing the PPH–SMM reduction initiative at the individual hospital level in relation to its hospital volume. Using raw data from Main et al's 2017 collaborative study,[5] we found that the estimated effects of implementing the PPH–SMM reduction initiative in the lowest-volume category were the largest: fewer than 1,000 deliveries per year, 44.52% reduction; 1,000–1,999 deliveries, 16.98% reduction; and 2,000 deliveries or more, 7.80% reduction. We assessed the cost effectiveness of implementing the PPH–SMM reduction initiative for hospitals in each category of annual volume, including both differences in effect and differences in per-birth cost of implementation (Fig. 3). Implementing the PPH–SMM reduction initiative was cost-saving across the entire volume range (400–7,000 births/year). Assuming implementation costs were twice those predicted, the costs of implementing the PPH–SMM reduction initiative remained less than $100,000 per QALY gained over the entire range.

Across the 100,000 samples in our probabilistic sensitivity analyses, implementing the PPH–SMM reduction initiative was found cost-saving in more than 83% of the samples, and cost effective at a willingness to pay threshold of $100,000 per QALY gained in 99% of the samples (see Appendix 1, http://links.lww.com/AOG/D2).

DISCUSSION

The CMQCC's PPH–SMM reduction initiative reduces adverse outcomes that present risks to person's health

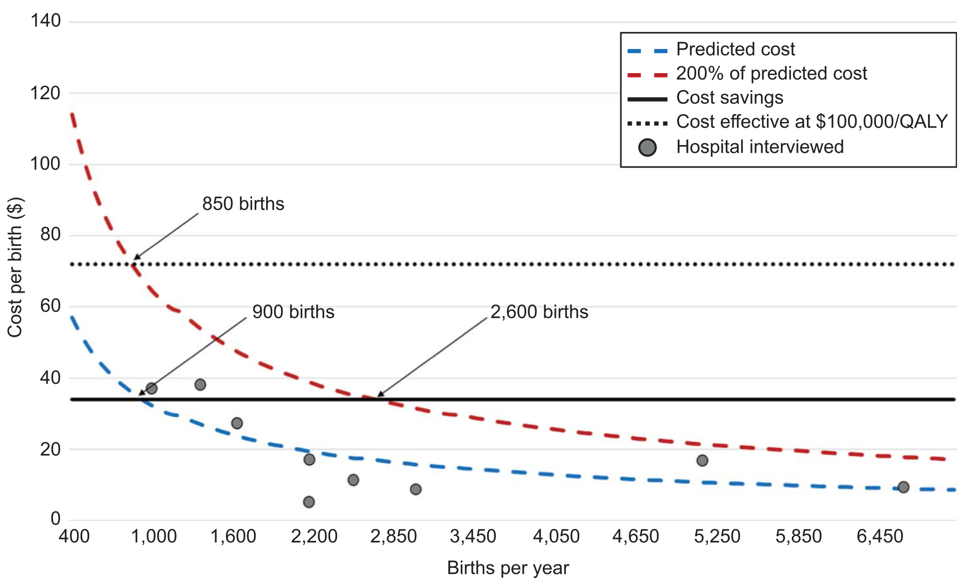

Fig. 2. Implementation cost vs hospital volume. Net cost determined by overall cost per birth minus the sum of the base case amount ($15.90) and base case cost savings ($17.78), where cost saving is $33.68 per birth and cost effective is $71.58 per birth. QALY, quality-adjusted life-year.

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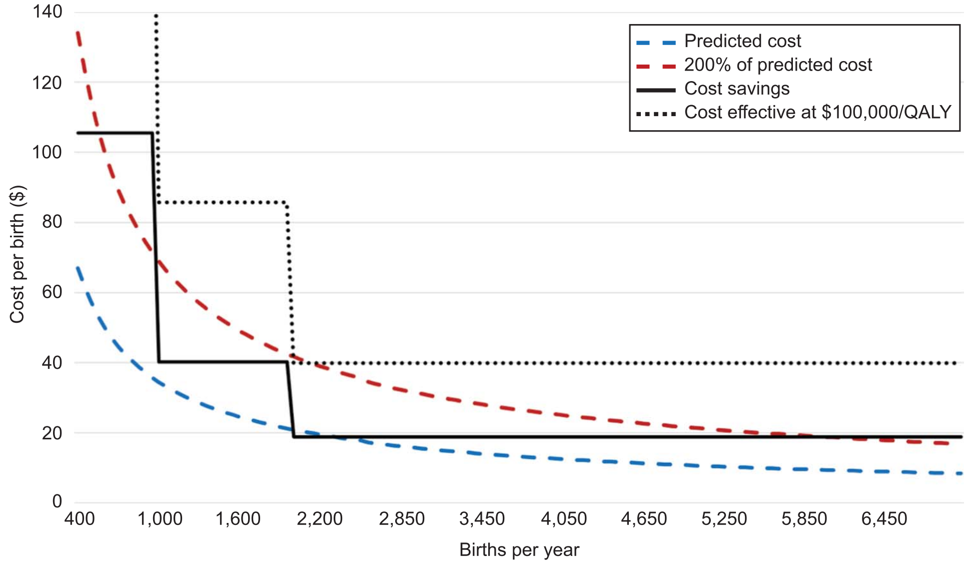

Fig. 3. Implementation cost, hospital volume, and intervention effectiveness. Dynamic cost-saving and cost-effectiveness thresholds estimated by differing the effectiveness of the postpartum hemorrhage–severe maternal morbidity reduction initiative across hospital birth volume. QALY, quality-adjusted life-year.

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and quality of life, yielding increased quality-adjusted life expectancy. We found that the costs of implementing the toolkit in all hospitals were offset by the averted costs of prevented adverse outcomes from PPH. Hence, implementation of the toolkit was cost effective and could avert one maternal mortality, 28 emergency hysterectomies, and save $9 million annually in hospital costs if implemented across California.

Across the United States, the annual volumes of births vary substantially among hospitals.[20] As the per-birth cost of implementing the PPH–SMM reduction initiative depends on the number of births over which the implementation cost is spread, birth volumes can influence cost effectiveness. Remarkably, the intervention remained cost effective within our sensitivity analysis across the entire range of hospital delivery volumes despite very different per-birth implementation costs and intervention effectiveness across these settings. Hospitals with very low birth volumes (fewer than 1,000 births annually) experienced higher intervention effectiveness, offsetting their higher per-birth implementation costs; hospitals with higher volume (more than 5,050 births annually) experienced lower per-birth implementation costs, offsetting their lower intervention effectiveness. This finding is of particular importance for lower-volume hospitals that–although making up nearly a third of hospitals nationally[20]–may traditionally suffer from selective implementation due to prohibitively high upfront or per-volume costs.

We used data on costs and effectiveness from a large implementation study[5] in the state of California. How these data may generalize to the United States is an important topic for further research. Studies in other regions of the United States that examine the use of PPH patient safety programs at a smaller scale – individual hospital[21] and hospital system[22]–have shown a reduction in rates of blood transfusion and maternal morbidities, suggesting our findings are plausible for a range of U.S. hospital settings and regions. With state perinatal collaboratives already in 47 states,[23] examination of implementation of the PPH–SMM reduction initiative within additional collaboratives would add further robustness to our findings. One major limitation to our study was the reliance on retrospective implementation cost data from a limited number of hospitals. The opportunity to prospectively collect implementation costs (in addition to outcomes) over a larger proportion of observed hospitals would help address this limitation.

California's statewide perinatal quality collaborative initiative to reduce SMM from PPH serves as an example of a cost-effective quality-improvement initiative that reduces the incidence of maternal morbidity and mortality, and potentially provides cost savings to the majority of birthing hospitals.

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PEER REVIEW HISTORY

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