Original Investigation

Relationship Between Cesarean Delivery Rate and Maternal and Neonatal Mortality

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IMPORTANCE Based on older analyses, the World Health Organization (WHO) recommends that cesarean delivery rates should not exceed 10 to 15 per 100 live births to optimize maternal and neonatal outcomes.

OBJECTIVES To estimate the contemporary relationship between national levels of cesarean delivery and maternal and neonatal mortality.

DESIGN, SETTING, AND PARTICIPANTS Cross-sectional, ecological study estimating annual cesarean delivery rates from data collected during 2005 to 2012 for all 194 WHO member states. The year of analysis was 2012. Cesarean delivery rates were available for 54 countries for 2012. For the 118 countries for which 2012 data were not available, the 2012 cesarean delivery rate was imputed from other years. For the 22 countries for which no cesarean rate data were available, the rate was imputed from total health expenditure per capita, fertility rate, life expectancy, percent of urban population, and geographic region.

EXPOSURES Cesarean delivery rate.

MAIN OUTCOMES AND MEASURES The relationship between population-level cesarean delivery rate and maternal mortality ratios (maternal death from pregnancy related causes during pregnancy or up to 42 days postpartum per 100 000 live births) or neonatal mortality rates (neonatal mortality before age 28 days per 1000 live births).

RESULTS The estimated number of cesarean deliveries in 2012 was 22.9 million (95% CI, 22.5 million to 23.2 million). At a country-level, cesarean delivery rate estimates up to 19.1 per 100 live births (95% CI, 16.3 to 21.9) and 19.4 per 100 live births (95% CI, 18.6 to 20.3) were inversely correlated with maternal mortality ratio (adjusted slope coefficient, −10.1; 95% CI, −16.8 to −3.4; $P = .003$) and neonatal mortality rate (adjusted slope coefficient, −0.8; 95% CI, −1.1 to −0.5; $P < .001$), respectively (adjusted for total health expenditure per capita, population, percent of urban population, fertility rate, and region). Higher cesarean delivery rates were not correlated with maternal or neonatal mortality at a country level. A sensitivity analysis including only 76 countries with the highest-quality cesarean delivery rate information had a similar result: cesarean delivery rates greater than 6.9 to 20.1 per 100 live births were inversely correlated with the maternal mortality ratio (slope coefficient, −21.3; 95% CI, −32.2 to −10.5, $P < .001$). Cesarean delivery rates of 12.6 to 24.0 per 100 live births were inversely correlated with neonatal mortality (slope coefficient, −1.4; 95% CI, −2.3 to −0.4; $P = .004$).

CONCLUSIONS AND RELEVANCE National cesarean delivery rates of up to approximately 19 per 100 live births were associated with lower maternal or neonatal mortality among WHO member states. Previously recommended national target rates for cesarean deliveries may be too low.

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Cesarean delivery is lifesaving for obstructed labor and other emergency obstetrical conditions; ensuring access to cesarean delivery is an essential strategy for meeting the Millennium Development Goals[1] and the forthcoming Sustainable Development Goals[2] for reducing child and maternal mortality. However, as a surgical procedure, there are risks of complications and overuse can be harmful to both mothers and neonates. Although the optimal population-level cesarean delivery rate is difficult to know, the World Health Organization (WHO) recommended that national rates not exceed 10 to 15 cesarean deliveries per 100 live births.[3] Despite this, cesarean delivery rates in many countries are substantially higher.[4,5]

Studies of the relationship between cesarean delivery rate and mortality have yielded inconsistent results.[6-8] In Latin American hospitals, increasing cesarean delivery rates from 10% to 20% was associated with greater preterm delivery and neonatal mortality.[8] In Asian hospitals, there was a higher risk of maternal mortality and morbidity from cesarean deliveries.[7] Conversely, in Africa, where the median cesarean delivery rate was 8.8%, the risk of neonatal death was lower in facilities having higher elective cesarean rates.[6] Three studies of cesarean delivery reported that cesarean rates of up to 10 to 15 cesarean deliveries per 100 live births were associated with optimal neonatal[5] and maternal mortality outcomes.[5,9,10] These studies were limited by either having incomplete data or relying on averaged cesarean delivery rates from multiple years without accounting for year-to-year variation in these estimates.

The purpose of this study was to provide better estimates for the relationship between cesarean delivery rates and neonatal and maternal mortality. Optimal cesarean rates associated with minimal maternal and neonatal mortality rates were estimated from the most recent data available and limited to estimates for a single year 2012.

Methods

Population and Health Databases

Population and health data were obtained for all 194 WHO member states from the World Bank World Development Indicators (WDI) database.[11] These data included total population, life expectancy at birth, percent urban population, gross domestic product (GDP) per capita, total health expenditure per capita, total fertility rate, and the national birth rate. Fifteen countries did not have all of these variables in the WDI database. In these instances, data were obtained from other sources, including the United Nations,[12] WHO,[13] and the Central Intelligence Agency.[14] Information was collected for 2012 and for the years 2005 through 2011, when 2012 data were not available. When total health expenditure per capita was not available for the year for which cesarean delivery data were obtained, either the subsequent or previous year's figure was used, in that order of preference (see Statistical Appendix in the Supplement for countries without recent total health expenditure data). Since health expenditure data were reported in US dollars by the World Bank, all expenditure figures were adjusted to 2012 US dollars using the consumer price index to account for inflation.[15]

Additional data obtained from the WDI database included 2012 neonatal mortality rate (neonates who die before reaching 28 days of age per 1000 live births), and the 2013 maternal mortality ratio (death from pregnancy-related causes while pregnant or up to 42 days postpartum per 100 000 live births).[11] Maternal mortality is typically presented as a ratio to live births since other measures of pregnancy not resulting in live births are usually not recorded by statistical agencies in any standardized way.[16]

Of the 194 WHO member states, 3 did not have neonatal mortality rate information and 13 did not have maternal mortality ratios. These countries were not included in the analysis evaluating the relationship between cesarean delivery rate and maternal and neonatal mortality. Maternal mortality ratio data were from 2013 since these ratios are only periodically reported and the closest year to 2012 for which data are available was 2013. The reliability of the data sources is discussed in the Data Source Appendix in the Supplement.

The institutional review board is not necessary for publicly available population-level statistics because it does not involve human subjects research.

Cesarean Delivery Data Sources

Country-level cesarean delivery rates for the most recent year in the period ranging from 2005 to 2012 were obtained from various sources, as described below (eTable 1 in the Supplement). Only the most recent cesarean delivery rate was used so that all countries only had one cesarean delivery rate used in this analysis. The Organization of Economic Co-operation and Development (OECD) Health Statistics Database,[17,18] the European Health for All Database (HFA-DB),[19] and the Demographic and Health Surveys (DHS) program database[20] were consulted first due to their quality assurance mechanisms and rigorous methods. If cesarean delivery rates differed by sources, the most recent data from the OECD, DHS, and HFA-DB were prioritized in that order. Other data sources included the WHO Global Health Observatory Data Repository,[21] The WHO World Health Statistics 2010 report,[22] the UNICEF Global Databases 2014,[23] health-related databases, and the peer-reviewed literature on PubMed. (See the Statistical Appendix for more details regarding sources of available data, and see Data Source Appendix for documentation for each of the primary and secondary data sources in the Supplement.) In particular, the DHS program methods have been previously described[24,25] and have been shown to be reliable.[26]

Building Models to Estimate Country-Level Cesarean Delivery Rates

The goal of this study was to relate 2012 population-level cesarean delivery rate with maternal mortality ratios and neonatal mortality rates. Cesarean delivery rate information for 2012 was available for 54 countries. For 118 countries, the one most recent cesarean delivery rate available was from 2005 to 2011. Twenty-two of the 194 countries did not have any cesarean delivery rate information for any of the years we studied.

Cesarean delivery rate was transformed with a base-10 logarithm because of nonnormally distributed data when performing multiple imputation. Population and health variables were transformed with a base-10 logarithm if they had a right-skewed distribution. Based on a previous study showing that total health expenditure per capita was the most strongly correlated variable with overall country-level surgical volume, and since cesarean delivery is a substantial component of this volume,[27] total health expenditure per capita was chosen a priori to be included in the model to predict cesarean delivery rate for countries without any data and for countries missing 2012 data but having data ranging from 2005 to 2011. The Spearman correlation was used to evaluate the relationship between observed cesarean delivery rate data and population and health variables. The variables were total health expenditure per capita, life expectancy at birth, GDP per capita, total population size, percent urban population, fertility rate, annual number of births, and birth rate. These were selected because the data were readily available and because they are potentially related to cesarean delivery rates. For the variables that were significantly correlated with cesarean delivery rate, we performed the Spearman correlation testing to assess if any of these population and health variables were collinear. Collinearity between these variables was assumed to be present if the correlation coefficient resulting from Spearman correlation testing was greater than 0.85. For collinear variables, we used the variable having a higher Spearman *r* for it and cesarean delivery rate in the model to predict 2012 cesarean delivery rate for 22 countries with missing cesarean delivery rate data and for 118 countries with cesarean delivery rate data available from 2005 to 2011 but not 2012. A nonparametric rank-regression approach[28] was used to examine the association between cesarean delivery rate and WHO region. (See the statistical appendix for results of the Spearman correlation testing in the Supplement.)

Countries with available cesarean delivery rate data were compared with countries without any available cesarean delivery rate data by fitting exact bivariable logistic regression models[29] to test whether the probability that missing cesarean delivery rate data was related to observed population and health data (see Statistical Appendix in the Supplement for further details).

Spline regression models were used to examine the relationship between log-transformed cesarean delivery rates (the outcome variable) and population and health variables (the predictors). These variables were selected for inclusion in the spline regression models based on the results of the Spearman correlation testing and the fitted exact bivariable logistic regression models. Cross-validation adjusted R^2 was used as a measure of model fit; first each country's cesarean delivery rate was predicted by a regression without that country, and the cross-validation adjusted R^2 was calculated as the square of correlation between the observed and predicted cesarean delivery rates, multiplied by a degrees-of-freedom correction. Spline regression models were distinguished from one another by the number of change-points (combinations of 0, 1, 2, or 3 change points) for each variable that was tested; the model with the maximum cross-validation adjusted R^2 was identified as the best fit.

Imputation of Cesarean Delivery Rates

For the 22 countries with no cesarean delivery rate data, 2012 cesarean delivery rates were imputed using the best predictive model that included total health expenditure per capita, fertility rate, life expectancy, percent of urban population, and region information (see Statistical Appendix in the Supplement for more details). For the 118 countries having a cesarean delivery rate from the years 2005-2011 but not 2012, regression was used to impute the 2012 rate using a predictive model that also included total health expenditure per capita, fertility rate, life expectancy, percent of urban population, and region information. Potential measurement error in the cesarean delivery rate data are described in the Statistical Appendix in the Supplement.

Evaluation of the Relationship Between Cesarean Delivery Rate and Mortality

After imputing the missing cesarean delivery rate data, spline regression models were subsequently fitted to nonparametrically explore the relationship between 2012 cesarean delivery rate estimates and 2013 maternal mortality ratio for countries with available maternal mortality data. For each of the 300 multiply imputed data sets, the regression models were fit between cesarean delivery rate and maternal mortality ratio and then the results were combined using the Rubin combining rule,[30] which estimates the multiple imputation variance by combining the variance within and across imputed data sets. Spline regression models were tested with 0 to 3 change points, using the maximum cross-validation adjusted R^2 to choose the number of change points. A similar analysis was performed for the relationship between 2012 cesarean delivery rate estimates and 2012 neonatal mortality rate for countries with available neonatal mortality data. The relationship between cesarean delivery rate estimates for 2012 with maternal and neonatal mortality was adjusted for total health expenditure per capita, fertility rate, percent of urban population, total population size, and WHO region. A sensitivity analysis was performed using countries with cesarean delivery rate data from the OECD and DHS only (n = 76) because these are relatively high-quality and uniform data sources. The above methods were used to evaluate the relationship between 2012 cesarean delivery rate estimates and maternal and neonatal mortality for these countries. A second sensitivity analysis was performed that excluded 9 countries with cesarean delivery rate data that came from the least reliable sources.

Accounting for Uncertainty in the Correlations Between Cesarean Delivery Rate and Mortality

Statistical inference for the multiply imputed data sets was performed using the approach of Rubin,[30] which estimates the multiple imputation variance by combining the variance within and across imputed data sets to make inferences about the relationship between cesarean delivery rates and maternal mortality ratios and between cesarean delivery rates and neonatal mortality rates. For each of the 300 data sets with imputed

Table 1. Comparison of Countries With and Without Available Cesarean Delivery Data

	Mean (95% CI)		
	Countries With Data (n = 172)	Countries Without Data (n = 22)	*P* Value[a]
Countries in sample, by WHO region, No. (%)			
African region	44 (26)	2 (9)	.02
American region	28 (16)	7 (32)	
Eastern Mediterranean region	19 (11)	3 (14)	
European region	51 (30)	2 (9)	
Southeast Asian region	10 (6)	1 (5)	
Western Pacific region	20 (12)	7 (32)	
Population size in 2012, millions	39.9 (18.3-61.5)	6.2 (0.7-11.7)	.21
Life expectancy in 2012, y	70.1 (68.7-71.5)	72.3 (68.6-76.0)	.29
Population living in urban areas in 2012, %	56.0 (52.5-59.5)	60.7 (50.7-70.7)	.38
Total fertility rate, births per woman in 2012[b]	2.9 (2.7-3.1)	2.5 (1.9-3.2)	.29
Mean annual No. of births in 2012, thousands	771 (403-1139)	147 (11-283)	.15
Birth rate, per 1000 people in 2012	22.3 (20.7-23.9)	19.0 (14.8-23.2)	.17
GDP per capita in 2012 in current US $	13 754 (10 252-17 255)	16 744 (9551-23 937)	.56
Total health expenditure per capita adjusted to 2012 US $	1069 (788-1350)	898 (543-1253)	.68

Abbreviation: GDP, gross domestic product.

[a] *P* values are derived from from exact bivariable logistic regression models.

[b] Fertility rate data for 2012 was available only for 188 countries (n = 168 for countries with data; n = 19 for countries without data).

cesarean delivery rates, the spline functions were fitted between cesarean delivery rates and maternal mortality ratios and between cesarean delivery rates and neonatal mortality rates. The multiple imputation estimate was the mean of the slopes and change points over all 300 imputations. The multiple imputation variance was calculated as the sum of the within- and between-imputation variances. Using the multiply imputed data sets and the Rubin approach for combining,[30] estimates of the overall global cesarean delivery volume and overall global cesarean delivery rate in 2012 and their corresponding 95% confidence intervals were generated. (See statistical appendix in the Supplement for further details.)

All statistical tests were performed with 2-sided *P* values. All *P* values <.05 were considered statistically significant. SAS version 9.2 (SAS Institute Inc) was used for all statistical analyses.

Results

The most recently available cesarean delivery data from the years 2005 through 2012 were used in this analysis for 172 of the 194 (88.7%) WHO member states (eTable 1 in the Supplement), which represented 97.6% of all live births in the world. Among the 172 countries with observed data, South Sudan had the lowest cesarean delivery rate (0.6%), while Brazil had the highest (55.6%). The most recent cesarean delivery rate data were available from the years 2010 through 2012 for 126 WHO member states, 2007-2009 for 37 WHO member states, and 2005-2006 for 9 WHO member states. Only the most recently available cesarean delivery rate was used for countries with available data.

Using exact bivariable logistic regression models,[29] the only population and health variable that was significantly associated with whether cesarean delivery rate data was missing among the 194 WHO member states was WHO region ($P = .02$) (**Table 1**). Because region was associated with whether cesarean delivery rate was missing, it was included in the final model that estimated cesarean delivery rate for countries with no cesarean delivery rate data.

The estimated global number of cesarean deliveries for 2012 was 22.9 million (95% CI, 22.5 to 23.2), yielding a global cesarean delivery rate estimate of 19.4 per 100 live births (95% CI, 18.5-20.3) (**Table 2**). eTable 2 in the Supplement lists the imputed (n = 22), extrapolated (n = 118), or observed (n = 54) estimates of cesarean delivery rate and volume with 95% CIs, total annual births, and total health expenditure per capita for all WHO member states in 2012.

Forty-five countries, accounting for 12.9% of the global population and 25.7% of global live births in 2012, had estimated cesarean delivery rates less than or equal to 7.2 per 100 live births (Table 2). Fifty-three countries, accounting for 22.4% of the global population and 15.9% of global live births in 2012, had estimated cesarean delivery rates higher than 27.3 per 100 live births. The 48 countries that were within the range of more than 7.2 to 19.1 per 100 live births accounted for 38.0% of the global live births in 2012.

Figure 1 shows the relationship between estimated cesarean delivery rates in 2012 and maternal mortality ratios in 2013 for the 181 countries with available maternal mortality data. The best fitting adjusted spline regression model had 3 change points (cross-validation adjusted $R^2 = 0.7768$) at cesarean delivery rates of 7.2 (95% CI, 4.4 to 10.1), 19.1 (95% CI, 16.3 to 21.9), and 27.3 (95% CI, 26.2 to 28.3) per 100 live births. With increasing cesarean delivery rates, maternal mortality decreased up to 7.2 per 100 live births or less (adjusted slope coefficient, −68.1; 95% CI, −89.2 to −46.9; $P < .001$; mean maternal mortality ratio, 463.3; 95% CI, 393.6 to 533.1 per 100 000 live births). This relationship was maintained, albeit somewhat attenuated, between 7.2 to 19.1 per 100 live births (adjusted slope coefficient, −10.1; 95% CI, −16.8 to −3.4; $P = .003$; mean maternal mortality ratio, 137.0; 95% CI, 100.4 to 173.5 per 100 000 live births. Estimated cesarean delivery

Table 2. Mean National Estimates for Countries According to Cesarean Delivery Rates, With Total Volume of Cesarean Deliveries for Each Category

	Cesarean Delivery Rate Groups per 100 Live Births, Mean (95% CI)[a]				Overall, Mean (95% CI)	
	≤7.2	>7.2-19.1	>19.1-27.3	>27.3	Total Global Cesarean Deliveries	Average Global Cesarean Delivery Rate
Countries, No.	45	48	48	53		
Share of global population in 2012, %	12.9	34.1	30.6	22.4		
Share of global live births in 2012, %	25.7	38.0	20.4	15.9		
Estimated cesarean delivery rate per 100 live births in 2012	4.4 (3.8-5.1)	13.3 (12.3-14.4)	23.7 (22.3-25.1)	35.3 (33.1-37.5)		19.4 (18.5-20.3)
Estimated volume of cesarean deliveries in millions in 2012	1.4 (1.3-1.4)	6.5 (6.4-6.7)	6.8 (6.6-6.9)	8.2 (8.0-8.4)	22.9 (22.5-23.2)	
Estimated of total volume of global cesarean deliveries in 2012, %	6.0 (5.7-6.4)	28.6 (27.6-29.7)	29.6 (28.4-30.8)	35.7 (34.3-37.2)		
Maternal mortality ratio per 100 000 live births in 2013[b]	463.3 (393.6-533.1)	137.0 (100.4-173.5)	35.9 (21.6-50.2)	36.7 (27.7-45.8)		
Neonatal mortality rate per 1000 live births in 2012[c]	30.2 (27.6-32.7)	17.3 (14.1-20.5)	6.7 (5.2-8.1)	6.3 (5.3-7.3)		
Total health expenditure per capita in 2012, US $	86 (36-136)	722 (314-1131)	1774 (1070-2478)	1509 (1031-1987)		

[a] Cesarean delivery rate groups are categorized by cesarean delivery rate per 100 live births. These categories are based on the relationship between cesarean delivery rates in 2012 and maternal mortality ratio in 2013.

[b] There were 13 World Health Organization (WHO) member states with missing 2013 maternal mortality ratio data (6 for >7.2-19.1, 1 for the >19.1-27.3, and 6 >27.3 the cesarean delivery rate groups).

[c] Three WHO member states were missing 2012 neonatal mortality rate data (2 for the >7.2-19.1; and 1 for the >19.1-27.3 cesarean delivery rate groups).

rates more than 19.1 per 100 live births were not correlated with maternal mortality ratios: for estimated cesarean delivery rates higher than 19.1 to 27.3 per 100 live births, the adjusted slope coefficient was 2.0 (95% CI, −5.0 to 9.1; P = .57) and the mean maternal mortality ratio was 35.9 (95% CI, 21.6 to 50.2) per 100 000 live births; for estimated cesarean delivery rates higher than 27.3 per 100 live births, the adjusted slope coefficient was 0.01 (95% CI, −3.58 to 3.60, P = .995) and the mean maternal mortality ratio was 36.7 (95% CI, 27.7-45.8) per 100 000 live births. The unadjusted analysis results were similar and are shown in the Statistical Appendix.

The best fitting spline regression model assessing the relationship between estimated cesarean delivery rate and neonatal mortality rate for 191 countries with available neonatal mortality data had 1 change point (cross-validation adjusted R^2, 0.7178; **Figure 2**). Neonatal mortality was lower for countries with increasing cesarean rate up to 19.4 (95% CI, 18.6 to 20.3) cesarean deliveries per 100 live births (adjusted slope coefficient, −0.8; 95% CI, −1.1 to −0.5, P < .001). Neonatal mortality was not associatied with cesarean delivery rates greater than 19.4 cesarean deliveries per 100 live births (adjusted slope coefficient, 0.006; 95% CI, −0.126 to 0.138; P = .93). The unadjusted analysis results were similar and are shown in the Statistical Appendix in the Supplement.

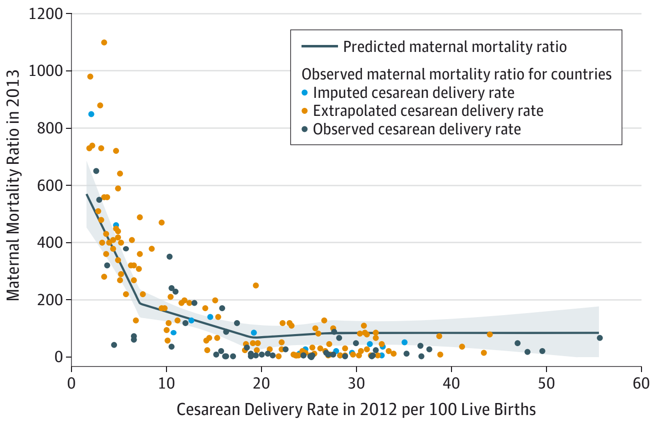
Sensitivity analyses were performed for 76 countries that have the highest-quality cesarean delivery rates available from the OECD (n = 25) and DHS (n = 51), with findings similar to the main analysis. Similar results were found using a data set that excluded the 9 countries with the least reliable data. Details of these analyses and results can be found in the Statistical Appendix in the Supplement.

Discussion

This analysis suggests that the optimal cesarean delivery rate may be higher than that previously estimated by the WHO.[31] The optimal cesarean delivery rate in relation to maternal and neonatal mortality was approximately 19 cesarean deliveries per 100 live births. The WHO recommendation that population-level cesarean delivery rates should not exceed 10% to 15% was a consensus opinion based on the observation that some countries with the lowest perinatal mortality rates had cesarean delivery rates that were less than 10 per 100 live births.[3]

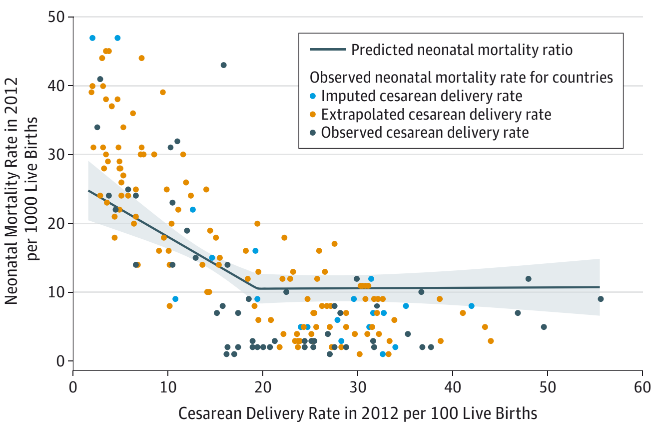
Prior studies suggesting that lower cesarean delivery rate thresholds were optimal for maternal[5,9,10] and neonatal mortality[5] were incomplete because they examined data from limited sets of countries and often examined outcomes in wealthier countries. Moreover, many studies used data from varying years without accounting for heterogeneity across years.[9,10,25,32] No study had cesarean delivery rate data for all 194 WHO member states.[9,10,25,32] The strength of the current study is the use of available data from 172 countries and inclusion of data estimated for a single year, 2012, and cesarean delivery rates for all WHO member states. By focusing the estimates to a single year, we avoided possible bias caused by using cesarean delivery rate data from varying years since cesarean delivery rates and mortality change over time.

Figure 1. Relation Between Maternal Mortality Ratio in 2013 and Cesarean Delivery Rate (per 100 Live Births) in 2012 for 181 Countries



Thirteen countries did not have maternal mortality ratio data for 2013. The maternal mortality ratio was derived from death from pregnancy-related causes while pregnant or up to 42 days postpartum per 100 000 live births. Change points correspond with the following cesarean delivery rates: 7.2, 19.1, and 27.3. The blue shade indicates 95% CIs. The curve was fit to the data by spline regression models using the maximum cross-validation–adjusted R^2 to choose the number of change points.

Figure 2. Relation Between Neonatal Mortality Rate (per 100 Live Births in 2012) and Cesarean Delivery Rate (per 100 Live Births) in 2012 for 191 Countries



Three countries did not have neonatal mortality rate data for 2012. The change point corresponds with a cesarean delivery rate of 19.4. The blue shade indicates 95% CIs. The curve was fit to the data by spline regression models using the maximum cross-validation–adjusted R^2 to choose the number of change points.

A better understanding is needed for how health systems can most efficiently develop comprehensive maternal and neonatal health care infrastructure. This includes supporting safe and appropriate provision of cesarean delivery and other obstetric surgical services with the intent of reducing maternal and neonatal mortality without causing overuse of procedures. The safe and appropriate provision of emergency obstetrical care is dependent on a health care system that can provide essential surgical care. Increasing the proportion of cesarean deliveries without attention to safety and quality within a functioning system of care may not result in improved health outcomes. Similarly, there are countries where very low maternal and neonatal mortality are obtained with relatively low cesarean rates, suggesting a complex interplay between overall maternal health resources, emergency obstetrical services, and other factors. Furthermore, the optimal cesarean delivery rate derived from this study may not apply to all countries because a certain level of nationally available resources may be required.

This study had certain limitations. Cesarean delivery rate data were obtained from many different sources. Most of the countries we studied had cesarean delivery rate information from sources commonly used in policy decisions and research studies. Twenty-two countries did not have cesarean delivery data and their rates were estimated using regression models. Cesarean delivery rates were not available for the year 2012 for 113 countries. Using regression models, 2012 cesarean delivery rates were estimated from rates available in the years 2005 through 2011. To our knowledge this is the first time multiple imputation modeling has been used to generate cesarean delivery rate estimates for countries with missing data. This method permits estimation of global cesarean delivery volume and cesarean delivery rate. Some data that might have been informative such as the percent of births attended by skilled health personnel (physicians, nurses, or midwives), proportion of deliveries at facilities, and clinician density were not included in the statistical models because these data were only available for some of the countries. Another limitation was the inability to fully assess the effect of measurement error when evaluating cesarean delivery rate as a covariate. When cesarean delivery rate is used as a covariate to predict maternal mortality ratios and neonatal mortality rates, measurement error could yield biased results, usually attenuated to the null. There are no available data to adjust for the possible measurement error (see Statistical Appendix in the Supplement), and thus the high correlations reported between cesarean delivery rates and maternal mortality ratios (cross-validation adjusted R^2 value of 0.7768 for the best maternal mortality spline model) and between cesarean delivery rates and neonatal mortality rates (cross-validation adjusted R^2 value of 0.7178 for the best neonatal mortality spline model) are likely conservative.

The findings herein were based on large, population-level databases from heterogeneous environments and have the attendant limitations on quality. However, the data that underlie the main findings of the analysis were from sources with rigorous methods and quality assurance practices; these same data are used by the majority of international policy and development agencies to make recommendations and monitor progress in maternal and child health. Multiple sensitivity analyses demonstrated that the findings were not driven by any particular data set and persisted when only the most robust data sources were included.

Due to the nature of ecologic analyses, causality cannot be inferred for the relationship between cesarean delivery rates and maternal and neonatal mortality. Furthermore, this study did not account for differences in cesarean delivery rates within populations that were due to regional variation, wealth disparity, or other factors. In developing countries, cesarean delivery rates in urban areas are up to 3 times higher than in rural districts.[33] There are large absolute differences in cesarean delivery rates based on wealth within countries surveyed by DHS.[34] In the United States, the variation in cesarean deliveries at the hospital level ranged from 7.1 to 69.9 per 100 live births in 2009,[35] some of which may be due to differential risks of obstructed labor, malpresentation, or other indications for cesarean delivery. A country's rate most likely reflects variation in practices and in patient risks, but how much of this variance is within a population is unknown. The contribution of patient factors to this significant variation in the United States was small, as was exemplified by the wide variability of cesarean delivery in lower-risk pregnancies.[35] Nevertheless, a risk-adjusted cesarean delivery rate may be suitable when discussing the appropriate level of obstetric surgical care. In addition, this analysis focuses exclusively on mortality as a health outcome. There may be additional benefits to increased access to cesarean delivery including reduction of morbidity due to complicated vaginal delivery, such as obstetrical fistulas, or abnormal connection between the vagina and other neighboring structures (eg, bladder or rectum) that occurs after prolonged and untreated obstructed labor. Conversely, there may be health burdens associated with more frequent cesarean delivery including short-term perioperative morbidity and long-term sequelae, such as small bowel obstruction, placenta accreta, and complications of subsequent pregnancies, a relationship that has been described in the United States.[36] This relationship has not been explored in settings with lower health resources. Despite these limitations, the findings of the current analysis highlight a significant correlation between cesarean delivery rate and lower mortality that merits attention in the development of policy to strengthen surgical components of health systems.

Conclusions

National cesarean delivery rates of up to approximately 19 per 100 live births were associated with lower maternal or neonatal mortality among WHO member states. Previously recommended national target rates for cesarean deliveries may be too low.

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Author Contributions: Drs Molina and Haynes had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Drs Weiser and Molina contributed equally to the article.
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Acquisition, analysis, or interpretation of data: Molina, Weiser, Lipsitz, Esquivel, Uribe-Leitz, Azad, Semrau, Berry, Gawande, Haynes.
Drafting of the manuscript: Molina, Weiser, Lipsitz, Haynes.
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