The value of intrapartum factors in predicting maternal morbidity

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BACKGROUND: The rates of severe maternal morbidity and mortality in the United States exceed those in other high-income nations. To aid providers and hospitals in recognizing the risk factors, there have been multiple attempts to develop stratification systems for morbidity based on maternal comorbidities. However, most women giving birth are healthy and do not have comorbidities to suggest that they are at an increased risk for severe maternal morbidity. There are small but inherent maternal risks to labor, and the events after admission may further influence a woman’s risk for morbidity even for those initially at a low risk.

OBJECTIVE: To determine if the incorporation of intrapartum factors known at the start of the second stage of labor improves the predictive performance of a comorbidity-based risk tool for severe maternal morbidity.

STUDY DESIGN: This is a retrospective cohort study of women at 8 hospitals in a single health system between July 1, 2016, and June 30, 2020. The women had term, singleton gestations and were admitted in labor and reached the second stage. The primary outcome was severe maternal morbidity. We compared logistic regression models using a validated risk-scoring tool (the Expanded Obstetric Comorbidity Score, which uses diagnosis codes for maternal comorbidities and pregnancy characteristics to predict maternal morbidity) with a model that included the Expanded Obstetric Comorbidity Score combined with parity and intrapartum factors. The intrapartum factors included labor induction or augmentation, length of labor, prolonged rupture of membranes, the presence of meconium-stained amniotic fluid, and gestational age. The hospitals were divided into a training (n=4) and testing (n=4) set to evaluate the predictive model performance. Discrimination was assessed by calculating the area under the receiver operating curve and calibration via calibration plots. Similar model comparisons were performed in a subgroup of women, who the Expanded Obstetric Comorbidity Score predicted to be at low risk for morbidity.

RESULTS: This analysis included 33,770 deliveries from the 8 hospitals; severe maternal morbidity occurred in 498 (1.5%) deliveries. The model performance is reported among the testing set (n=15,350). Using the Expanded Obstetric Comorbidity Score alone, the area under the receiver operating curve was 0.676 (95% confidence interval, 0.636−0.716) and 155 (71%) events occurred among individuals above the median predicted risk. When combining intrapartum factors, the area under the receiver operating curve increased to 0.729, (95% confidence interval, 0.693−0.764) and 171 (78%) events occurred among individuals above the median predicted risk. The significant factors that were associated with severe maternal morbidity in this combined model included the Expanded Obstetric Comorbidity Score, length of labor, and the presence of meconium-stained amniotic fluid. The area under the receiver operating curve for the model with intrapartum factors was significantly higher than the models using the Expanded Obstetric Comorbidity Score alone (P<.001).

CONCLUSION: The incorporation of intrapartum factors along with a validated risk tool (Expanded Obstetric Comorbidity Score) improved the ability to predict severe maternal morbidity at the start of the second stage. These findings emphasize the evolution of a woman’s risk during her labor course and suggests that the prediction of maternal risk can be improved by considering intrapartum factors.

Key words: delivery, intrapartum, maternal morbidity, maternal mortality, risk prediction, risk stratification, risk tool

Introduction

The rates of severe maternal morbidity and mortality in the United States exceed those in other high-income nations. To aid providers and hospitals in recognizing the risk, there have been multiple attempts to develop stratification systems for maternal morbidity. Most have aimed to stratify the risks based on maternal medical comorbidities and pregnancy characteristics that are known before or at the time of presentation for delivery; this may help providers better anticipate and prepare for an adverse maternal event. These preadmission risk stratification tools may be helpful in the implementation of the Levels of Maternal Care hospital designation system by identifying which patients might be appropriate for referral or transfer to a higher level of care facility. However, most women are low-risk, and these tools may fail to update or acknowledge how the risk may change after admission. Similarly, these types of comorbidity-based tools may not appropriately acknowledge issues with unmeasured confounding and racial/ethnic disparities that exist in pregnancy outcomes. Lastly, their utility may be limited by poor positive predictive values and the subsequent effects of “over-identifying” people at risk.

There have been efforts to translate these preadmission tools for use in women admitted to labor and delivery. However, most of the women giving birth are healthy and do not have comorbidities to suggest that they are at increased risk for severe maternal morbidity (SMM). There are small but inherent maternal risks to labor, and the events after admission may further influence a woman’s risk for morbidity, even for those initially at low risk.


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As many comorbidity-based risk tools are being developed, the findings of this study emphasize the evolution of a woman’s risk of morbidity during her labor course and suggest that the prediction of maternal risk can be improved by considering intrapartum factors.

Materials and Methods
This was a retrospective cohort study of women with term, singleton gestations admitted in labor in a single health system between July 1, 2016, and July 20, 2020. The system is comprised of 2 university-based referral centers and 6 affiliated hospitals. Women and their pregnancy details were identified using the data entered into the electronic health record (EHR) by clinical providers. The hospitals began contributing deliveries to the data set at the start of the study period (n=3) or once they adopted the common EHR system (Epic): n=4 in 2017, n=1 in 2019. All intrapartum risks and delivery information were ascertained from the delivery summary report within the EHR, a standardized form required to be completed after deliveries across all institutions, and the associated International Classification of Disease, Tenth Revision, (ICD-10) diagnosis codes assigned to the delivery encounter. The delivery summary report serves as the primary source of information for the birth certificate; this information is manually entered and verified by the delivering nurse and clinician at the time of delivery.

The objective of this project was to assess the intrapartum risks at the start of the second stage. For many patients, especially those who are nulliparous, the ultimate mode of delivery (cesarean or vaginal delivery) is unknown. Thus, this time frame was selected as a clinically relevant point in which a patient’s risk could be reassessed, discussed among team members, and appropriately planned for before the pushing and delivery. Thus, for inclusion into the study, women had to have a second stage time listed in the EHR. For women with missing second stage times who were known to have entered the second stage based on having a vaginal delivery or a cesarean delivery with the indications of failed operative delivery or arrest of descent, the second stage times were imputed using multiple imputation based on the following known characteristics: maternal age, race, parity, gestational age, induction and augmentation status, mode of delivery, birthweight, birth year, and hospital (n=2657 or 4.3% of the entire data set).

The primary outcome of interest was SMM as defined by the Centers for Disease Control and Prevention. The ICD-10 diagnosis and procedure codes for this commonly used definition are published online. The Expanded Obstetric Comorbidity Score (EOCS), which is published and validated by Leonard et al. for the prediction of SMM using the ICD-10 data, was used as the baseline method for risk stratification. This score assigns a weight to the maternal comorbidities and pregnancy characteristics, ranging from 1 for gestational diabetes to 59 for placenta accreta spectrum disorders; the overall sum of the weights for the individual components was shown to be associated with an increased risk of SMM. It was shown to have an area under the curve (AUC) of 0.82 in a national data set. It was not designed specifically for women in labor or to consider intrapartum factors or events, which cannot be easily ascertained from diagnosis codes.

We determined that the following events during a woman’s labor course may influence or be associated with their risk of SMM and should be known at the start of the second stage of labor such that a revised risk could be calculated before delivery: labor induction or augmentation, length from admission to the start of the second stage, prolonged rupture of membranes (defined as ≥24 hours from the rupture of membranes to the start of the second stage), the presence of meconium-stained amniotic fluid (a finding that may alter provider decision-making regarding urgency or mode of delivery), and gestational age (categorized by week). Of note is that we categorized the length of admission to the start of the second stage in 6-hour segments, as the strength of its relationship with morbidity was hypothesized to vary by time; 6-hour segments were chosen a priori in an effort to balance the granularity and sample size in each bin. Similarly, we also included parity, which is not reliably ascertained from ICD-10 diagnosis codes. There were no missing data with
the exception of prolonged rupture of membranes (n=2325 or 6.8% of the final cohort). When missing, this dichotomous variable of prolonged rupture was imputed via multiple imputation by chained equations (m=5) based on the other known variables included in the analysis. These intrapartum characteristics were compared among women with and without SMM using 2-sided t tests, Wilcoxon rank sum tests, and chi-squared tests where appropriate.

We grouped the hospitals into a training and testing set. Each group contained an academic referral center, a large (≥1000 deliveries per year) community-based hospital, and 2 smaller (<1000 deliveries per year) community-based hospitals. The set with the largest number of deliveries was used as the training set. We chose the approach of splitting the hospitals, rather than patients, into 2 groups to strengthen the evidence of the model’s generalizability (ie, the demonstration of external hospital validity rather than internal validity). All models and predictions were generated in the training set and then validated in the testing set.

We first tested the performance characteristics of the EOCS as an external validation of this score in women with a singleton term gestation and planned vaginal delivery. Logistic regressions were performed using SMM as the outcome and the continuous EOCS as the exposure variable. Next, we investigated the role of intrapartum factors without considering maternal comorbidities. A prespecified multivariable logistic regression model in the training set was used to generate predictive probabilities for SMM for the entire data set. The prespecified model contained all the intrapartum risk factors of interest. Lastly, to compare the combined effect of maternal comorbidities with intrapartum factors, the continuous EOCS variable was added to the intrapartum model.

Traditional logistic regression models were used, as opposed to more automated variable selection techniques, to generate easily interpretable odds ratios (ORs). To minimize the effects of overfitting in the models, the ratio of the number of predictors to the observed outcome events were limited to at least 10:1. In accordance with the Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD) reporting guidelines for predictive models, discrimination was assessed by calculating the AUC for the standard receiver operating curve, and calibration was assessed by comparison of the actual vs predicted risks when grouped into deciles of predicted risk. We compared the performance of models using 2 approaches as follows: (1) We tested the equality of receiver operator curves using the method as described by DeLong et al and (2) We calculated the fraction of new diagnostic information added by comparing the variance of the predicted values in the testing set as described by Harrell.

As an exploratory secondary analysis, we also used the same predictive modeling methods in the subgroup of women at a low risk for SMM. Those considered to be at low risk had an EOCS less than the median score among the cohort (EOCS ≤2). Only the 2 following conditions in the EOCS had a weight ≤2: maternal age ≥35 years (weight=2) and gestational diabetes (weight=1). Thus, women with 1 but not both of these conditions, in addition to women with no comorbidities, were considered low-risk. The SMM event number (n=147) was too low in this subgroup to divide into a training and testing set. Thus, the AUC and calibration plots were generated for the overall cohort only.

A sensitivity analysis was performed using a complete case analysis design, in which multiple imputation was not used to estimate the missing values. Observations with missing second-stage times or length-of-rupture times were excluded.

This project was approved by the Partners Healthcare Human Research Committee. The analysis was performed using Stata Statistical Software Release 16.0 MP (StataCorp LLC, College Station, Texas).
Results

This analysis included 33,770 deliveries from the 8 hospitals (Figure 1). The average annual number of deliveries meeting the eligibility criteria at each hospital ranged from 55 to 2419. Of these 33,770 deliveries, 18,420 (55%) were assigned to the training set and 15,350 (45%) to the testing set. There were 498 cases of SMM (1.5%)—280 (1.5%) and 218 (1.4%) in the training and testing sets, respectively (P=.45). The EOCS ranged from 1 to 141, with a median EOCS of 2 (interquartile range, 0–14). Those with scores less than or equal to the median (EOCS ≤2) were considered low-risk (n=17,648). Of these women, 12,502 (71%), had an EOCS equal to 0.

Table 1 compares the characteristics of women with and without SMM in the training set. Those who experienced SMM were more likely to be nulliparous (66.8% vs 55.0%; P<.001), have labor induced (45.4% vs 32.0%; P<.001), and have meconium-stained amniotic fluid (P=.001) than those who did not experience SMM. Notably, women with SMM also had a higher EOCS (median 16 vs 2; P<.001) and longer labors (median 17.3 vs 10.6 hours; P<.001).

Table 2 shows all the variables that were included in the model for both EOCS and intrapartum factors. It also compares the unadjusted and adjusted odds of SMM in the training set for the model with the EOCS and intrapartum factors. All the factors were positively associated with SMM in the unadjusted analysis. However, in the adjusted analysis, only the 3 following factors were significantly associated with SMM: EOCS (OR, 1.04; 95% confidence interval [CI], 1.03–1.05), interpreted as a 1.04 increase in the odds of SMM for every point increase in the EOCS; the length of labor, where the odds of SMM increased stepwise with each 6-hour increment of time; and the presence of meconium-stained amniotic fluid (OR, 1.39; 95% CI, 1.04–1.84).

In the model using the EOCS alone, the areas under the receiver operating characteristic curve were 0.676 (95% CI, 0.642–0.711) and 0.676 (95% CI, 0.636–0.716) in the training and testing sets, respectively. In the test set, 63 (29%) cases of SMM occurred in the lowest-risk half and 155 (71%) in the highest-risk half. In comparison, the models using intrapartum factors without other maternal comorbidities had AUCs of 0.671 (95% CI, 0.638–0.703) and 0.633 (95% CI, 0.592–0.673) in the training and testing sets, respectively. In the test set, 72 (33%) cases of SMM occurred in the lowest-risk half and 146 (67%) in the highest-risk half.

When combining intrapartum factors with EOCS, the AUC increased to 0.735 (95% CI, 0.705–0.766) in the training set and 0.729 (95% CI, 0.693–0.764) in the testing set using the prespecified logistic regression model. In the test set, 47 (22%) cases of SMM occurred in the lowest-risk half and 171 (78%) in the highest-risk half. For this combined model, the AUC in the test set was significantly higher than that in the model using the EOCS alone (P=.003 for test of equality) (Figure 2). When comparing the variances of the predicted probabilities between the 2 models, the fraction of diagnostic information added by incorporating the intrapartum factors was 0.29 (or 29%). All the models showed similar calibration, suggesting that improved discrimination was not at the expense of calibration (Figure 3).

The calibration plots revealed a group of people at a significantly greater risk than others, specifically those in the top decile of the predicted risk. In the combined EOCS and intrapartum factor model, the sensitivity and specificity for SMM was 35.3% and 90.4%, respectively, for those in the top decile of the predicted risk. The positive and negative predictive values for SMM using this threshold were 5.1% and 99.0%, respectively. The baseline incidence of SMM in the group below the top decile threshold was 1.0%.

In the subgroup of low-risk women, the AUC was 0.510 (95% CI, 0.471–0.547) when using the EOCS alone.
The calibration plots revealed no distinction in risk grouping using the EOCS, as its range was restricted from 0 to 2. With the addition of intrapartum factors, the AUC increased to 0.707 (95% CI, 0.665–0.748), which was significantly higher than the AUC using the EOCS alone (P<.001). The fraction of diagnostic information added with the intrapartum factors was calculated to be 1.0 (or 100%). The calibration plots reveal improved prediction fits in comparison with the model using EOCS alone (Figure 4).

The sensitivity analysis using only the observations with complete data resulted in similar findings. The test set AUCs for the models using the EOCS alone, intrapartum factors alone, and combined EOCS and intrapartum factors were 0.681 (95% CI, 0.640–0.722), 0.635 (95% CI, 0.592–0.676), and 0.731 (95% CI, 0.696–0.767), respectively.

**Comment**

**Principal findings**
The EOCS was not developed using EHR data or in any specific subset or cohort of deliveries, limiting its use primarily to research purposes or population health monitoring as a method of risk adjustment.7 If it were to be translated into clinical practice as a risk stratification tool, as has been done with the Obstetric Comorbidity Index, studies would be needed to show how it may perform in a prospective application.5 Among laboring women at term with singleton gestations who reach the second stage, we demonstrated that the EOCS performed modestly for the prediction of SMM. The AUC of 0.676 was notably lower than the AUC of approximately 0.80 from the original study, likely owing to the differences in the cohorts between the 2 groups.7 However, we demonstrated that the incorporation of intrapartum factors with the EOCS outperformed the other models. These findings emphasize the evolution of a woman’s risk during her labor course and suggests that a more accurate prediction of risk can be generated by including intrapartum events in combination with comorbidities.

The availability of large population data sets, such as claims data, and the emergence of EHR data have fueled risk prediction models in multiple medical specialties, including obstetrics.4–7,23 To date, most have focused on predicting maternal morbidity using underlying or pregnancy-related comorbidities, largely those that are known before the delivery admission.4,5,7 Most related to our work were the models presented by Rosenbloom et al.6 In their cohort of over 19,000 laboring women at term, they demonstrated that the inclusion of intrapartum factors with several antepartum factors resulted in a prediction model with a discrimination of 0.76. We report a similar AUC in our cohort of laboring women at term.

However, our approach differs in an important aspect. We intentionally designed our model to estimate the risk at the start of the second stage rather than incorporating the mode of delivery into the risk prediction. The weighted score for cesarean delivery in the Rosenbloom model was 4-fold higher than other comorbidities included in the model.6 As most morbidity is delivery-
related and the ultimate mode of delivery (rather than planned mode) is not known in labor, especially among nulliparous women, we believe that the prediction models including the mode of delivery as a risk factor limit their application in clinical practice if deployed and updated during labor.

Clinical implications
We selected the start of the second stage as a time point to evaluate the cumulative effects of intrapartum risk factors known before delivery. Although we understand that a reassessment of risk is not always feasible owing to clinical circumstances at this time, there is a clear transition in the actions and the plan for the patient and provider behaviors between the first and second stages of labor. A natural extrapolation of this work would be the generation of a weighted-risk tool or score that could be used among the provider teams to identify women at the highest risk for delivery-related morbidity, standardize the communication of that risk, and then discuss and prepare strategies and resources to reduce or prevent morbidity.

Importantly, we demonstrated that many women are not predicted to be at an increased risk of morbidity based on their known comorbidities. Approximately 40% of the women in our cohort who attempted a vaginal delivery had an EOCS of 0, even in a health system in which over 60% of the deliveries occurred at the 2 academic referral centers. However, among these women, their risk can be further stratified by considering intrapartum factors. These findings suggest that although the tools designed to estimate the risk based on medical comorbidities or pregnancy characteristics have utility in stratifying risk at the time of admission, they may be less applicable for women in labor as they accrue labor-related risks of morbidity such as chorioamnionitis. Over-reliance on these types of comorbidity-based tools may cause providers to underestimate the risks in labor. A tool incorporating intrapartum factors may prove beneficial for patients by ensuring that the care teams are oriented and prepared for a patient’s evolving risk status during labor, which may span multiple shift changes and handoffs.

Research implications
This work serves as a precursor to the development of accurate and validated risk stratification systems that can be used for women in labor. By demonstrating the value of the intrapartum factors, the risk stratification tools based on prospectively collected or EHR data can be developed and tested to aid providers in recognizing the risk and potentially intervening to avert morbidity. More work is needed to identify how risk stratification systems can be appropriately and effectively incorporated into clinical practice, including prospective validating of the model, determining the physical mechanics of deriving the risk score in a timely manner, and examining the intended and inadvertent effects of a risk score on provider actions. Furthermore, to optimize their performance and utility, the choice of the risk model may ultimately need to be dynamic given the clinical scenario (eg, different tools based on the planned mode of delivery or phases of peripartum care, such as predelivery and postdelivery).

Strengths and limitations
The strengths of this study include its large sample size and the inclusion of patients from 8 hospitals of varying types, increasing the generalizability of the results. Similarly, we used the validated EOCS to summarize and weigh the comorbidities in our prediction model and compare them with intrapartum factors. In choosing the intrapartum factors for inclusion, we limited our analysis to those that would be
The figure compares the calibration plots for the following 3 models: (1) using the EOCS alone, (2) using intrapartum risk factors, and (3) using the EOCS combined with intrapartum risk factors. The intrapartum risk factors in the model included the following: nulliparity, labor induction or augmentation, length from admission to start of second stage, prolonged rupture of membranes, the presence of meconium-stained amniotic fluid, and gestational age.

EOCS, Expanded Obstetric Comorbidity Score.

The figure compares the calibration plots for the following 2 models in a subgroup of women at a low risk for severe maternal morbidity, defined as those with scores ≤2 (median): (1) using the EOCS alone, and (2) using the EOCS with intrapartum risk factors. The intrapartum risk factors in the model included the following: nulliparity, labor induction or augmentation, length from admission to start of second stage, prolonged rupture of membranes, the presence of meconium-stained amniotic fluid, and gestational age.

EOCS, Expanded Obstetric Comorbidity Score.
known at the start of the second stage of labor to demonstrate the practicality and utility of this tool for women in labor, rather than with the hindsight of the mode of delivery or the second stage length. We cannot assume that these models would perform similarly at different time points during a woman’s labor course. Although multiple imputation was used when possible, we ultimately excluded 2.6% of the samples, because their second stage time was unable to be imputed; in doing so, we potentially excluded some women who did reach the second stage, though they are likely only a fraction of the total excluded.

**Conclusions**

The intrapartum factors influence a patient’s risk for maternal morbidity. Comorbidity-based stratification tools can be used to establish the risk before or at the time of admission, which may facilitate transfer to a higher level of care center or consultation with a subspecialty provider. However, once a patient is admitted and in labor, intrapartum factors should be included in the risk tools to aid in the recognition and preparedness for the risk of maternal morbidity. The increasing availability of EHR data and the ability of the information systems to incorporate these types of tools will allow for the development of more nuanced risk stratification tools, such as tools for women with a planned cesarean delivery vs a planned vaginal delivery and using more granular patient information than can be obtained from hospital claims data.

**References**


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