OBSTETRICS

# Prediction of vaginal birth after cesarean delivery in term gestations: a calculator without race and ethnicity



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**BACKGROUND:** Investigators have attempted to derive tools that could provide clinicians with an easily obtainable estimate of the chance of vaginal birth after cesarean delivery for those who undertake trial of labor after cesarean delivery. One tool that has been validated externally was derived from data from the Maternal-Fetal Medicine Units Cesarean Registry. However, concern has been raised that this tool includes the socially constructed variables of race and ethnicity.

**OBJECTIVE:** This study aimed to develop an accurate tool to predict vaginal birth after cesarean delivery, using data easily obtainable early in pregnancy, without the inclusion of race and ethnicity.

**STUDY DESIGN:** This was a secondary analysis of the Cesarean Registry of the Maternal-Fetal Medicine Units Network. The approach to the current analysis is similar to that of the analysis in which the previous vaginal birth after cesarean delivery prediction tool was derived. Specifically, individuals were included in this analysis if they were delivered on or after 37 0/7 weeks' gestation with a live singleton cephalic fetus at the time of labor and delivery admission, had a trial of labor after cesarean delivery, and had a history of 1 previous low-transverse cesarean delivery. Information was only considered for inclusion in the model if it was ascertainable at an initial prenatal visit. Model selection and internal validation were performed using a cross-validation procedure, with the dataset randomly and equally divided into a training set and a test set. The training set was used to identify factors associated with vaginal birth after cesarean delivery and build the logistic regression predictive model using stepwise backward elimination. A final model was generated that included all variables found to be significant ($P<.05$). The accuracy of the model to predict vaginal birth after cesarean delivery was assessed using the concordance index. The independent test set was used to estimate classification errors and validate the model that had been developed from the training set, and calibration was assessed. The final model was then applied to the overall analytical population.

**RESULTS:** Of the 11,687 individuals who met the inclusion criteria for this secondary analysis, 8636 (74%) experienced vaginal birth after cesarean delivery. The backward elimination variable selection yielded a model from the training set that included maternal age, prepregnancy weight, height, indication for previous cesarean delivery, obstetrical history, and chronic hypertension. Vaginal birth after cesarean delivery was significantly more likely for women who were taller and had a previous vaginal birth, particularly if that vaginal birth had occurred after a previous cesarean delivery. Conversely, vaginal birth after cesarean delivery was significantly less likely for women whose age was older, whose weight was heavier, whose indication for previous cesarean delivery was arrest of dilation or descent, and who had a history of medication-treated chronic hypertension. The model had excellent calibration between predicted and empirical probabilities and, when applied to the overall analytical population, an area under the receiver operating characteristic curve of 0.75 (95% confidence interval, 0.74—0.77), which is similar to the area under the receiver operating characteristic curve of the previous model (0.75) that included race and ethnicity.

**CONCLUSION:** We successfully derived an accurate model (available at https://mfmunetwork.bsc.gwu.edu/web/mfmunetwork/vaginal-birth-after-cesarean-calculator), which did not include race or ethnicity, for the estimation of the probability of vaginal birth after cesarean delivery.

**Key words:** calculator, calibration, personalized, prediction, trial of labor after cesarean delivery, vaginal birth after cesarean delivery, validation

## Introduction

After peaking in the late 1990s, vaginal birth after cesarean delivery (VBAC) rates dropped significantly in the United States and continue to remain below 10%.[1] This decline has been attributed largely to a decline in the frequency with which individuals choose to undergo trial of labor after cesarean delivery (TOLAC).[2] One analysis performed in the years following the VBAC peak revealed that the magnitude of the decline in TOLAC was similar regardless of the likelihood that an individual would have a VBAC if they undertook TOLAC.[2]

The choice to undertake a TOLAC should be person centered and a product of shared decision making that incorporates the individual's values and preferences.[3,4] Ideally, the decision process regarding the approach to delivery should be started early in pregnancy, and part of that process should be the provision of information, such as the likelihood that a VBAC will occur if TOLAC is undertaken. Although one approach is to provide a population-level estimate of the probability of VBAC, another approach is to provide a more individualized estimate.

Accordingly, investigators have attempted to derive tools that could be used to provide clinicians with an easily obtainable estimate of VBAC for those who undertake TOLAC.[5—8] One

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## AJOG at a Glance

### Why was this study conducted?

A commonly used tool to estimate the chance of vaginal birth among those undergoing trial of labor after 1 previous cesarean delivery includes race and ethnicity as input variables. There are concerns that their inclusion reifies a biologic construct of race and ethnicity and may perpetuate health disparities.

### Key findings

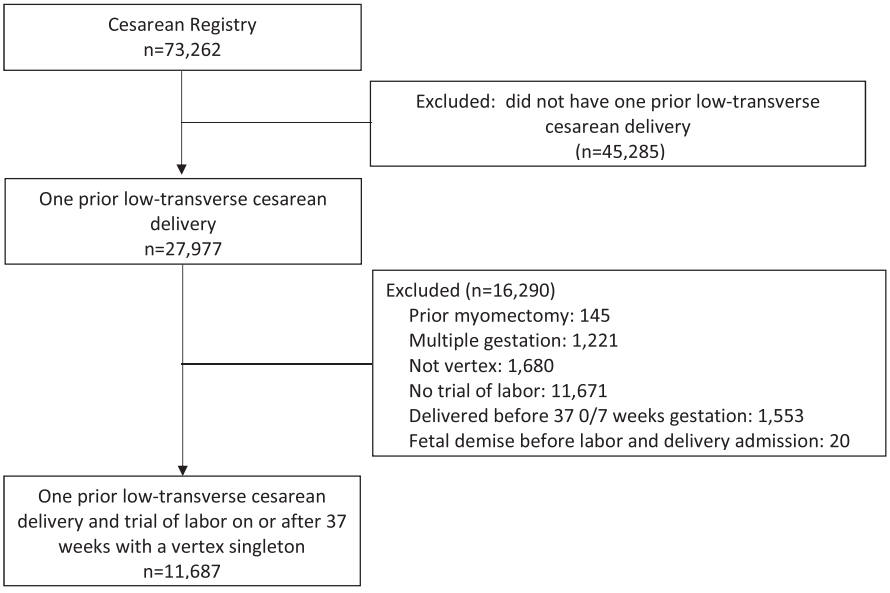
A prediction model that only uses information available at the first prenatal visit but does not include race and ethnicity was developed. The new model included age, height, prepregnancy weight, occurrence of a previous vaginal birth, arrest indication for previous cesarean delivery, and history of chronic hypertension. The new model had excellent calibration between predicted and empirical probabilities and, when applied to the overall analytical population, an area under the receiver operating characteristic curve (AUC) of 0.75 (95% confidence interval, 0.74–0.77), which is similar to the AUC of the previous model (0.75) that included race and ethnicity.

### What does this add to what is known?

This study provides a newly developed tool for the estimation of the probability of vaginal birth for those undergoing trial of labor after cesarean delivery that can be used in shared decision making.

internally validated tool that subsequently has been validated externally in multiple different locations at temporally distinct times was derived from data from the Maternal-Fetal Medicine Units (MFMU) Cesarean Registry.[9–16] However, this tool included the socially constructed variables of race and ethnicity, and there is concern that their inclusion may reify a biologic construct of race and ethnicity and perpetuate health disparities.[17–19] Therefore, this analysis was designed to determine whether an internally validated tool to accurately predict VBAC using data easily obtainable early in pregnancy, without the inclusion of race and ethnicity, could be derived using the same MFMU dataset.

**FIGURE 1**
**Flowchart**




Flowchart of eligibility for inclusion in this secondary analysis.

*Grobman et al. Prediction of vaginal birth after cesarean delivery. Am J Obstet Gynecol 2021.*

## Methods

This was a secondary analysis of the Cesarean Registry of the *Eunice Kennedy Shriver National* Institute of Child Health and Human Development MFMU Network. The registry included all individuals with a history of cesarean delivery who were admitted for delivery to centers within MFMU-participating centers between 1999 and 2002. Full details of this study have been described previously.[20] In brief, trained and certified research nurses abstracted medical records of women who were identified as having had any history of cesarean delivery. Abstracted data included demographic, historic, and peripartum factors. Approval for the study was obtained from the institutional review board of each institution, and a waiver of informed consent was obtained.

The general approach to the current analysis is similar to that of the analysis in which the previous VBAC prediction tool was derived.[9] Specifically, women were included in this analysis if they were delivered on or after 37 0/7 weeks' gestation with a live singleton fetus in the cephalic presentation at the time of labor and delivery admission, had a TOLAC, and had a history of 1 previous low-transverse cesarean delivery. Women were excluded if they had a previous myomectomy. Given the value of beginning counseling early in pregnancy, information was only considered for inclusion in the model if it was ascertainable at an initial prenatal visit. Such factors included demographic characteristics (age, height, prepregnancy weight, prepregnancy body mass index), medical conditions existing before pregnancy (chronic hypertension treated with medication before and during pregnancy, diabetes mellitus, asthma, thyroid disease, seizure disorder, renal disease, cardiac disease, connective tissue disease), and obstetrical history

(presence of previous vaginal delivery, arrest disorder as the indication for previous cesarean delivery, and maximum birthweight of previous child). If an individual had a previous vaginal delivery, it was further characterized by whether it had occurred after the previous cesarean delivery, with no previous vaginal birth used as the referent. An arrest disorder for cesarean delivery was considered to exist when the primary indication for a previous cesarean delivery was an arrest of dilation or descent and included those indications coded as "failed induction."

Model selection and internal validation were performed using a cross-validation procedure. All individuals meeting the eligibility criteria (ie, 1 previous low-transverse cesarean delivery and trial of labor on or after 37 weeks' gestation with a vertex singleton) were randomly divided into a mutually exclusive training set (n=5741) and test (validation) set (n=5946). The training set was used to identify factors associated with VBAC and build the logistic regression predictive model, which was developed using stepwise backward elimination with the inclusion of all factors found to be significant ($P<.05$). In addition, linear and quadratic terms for continuous variables and 2-way interactions were evaluated for inclusion in this model.

Moreover, the individuals in the test set were used to estimate classification errors and validate the model that had been developed using the training set, with calibration assessed graphically. The predicted probabilities of VBAC using the test set were calculated and partitioned into deciles. In each decile, the proportion (and the corresponding 95% confidence interval [CI]) of individuals who had a VBAC was calculated. These proportions represent the observed (empirical) probability of VBAC. Penalized B-spline curves for the proportions and CIs were then generated on the basis of the predicted and observed probabilities for each decile category.

Final estimates of the coefficients for each factor in the logistic regression predictive model were determined using all individuals included in this analysis (ie, the overall analytical population).

**TABLE 1**
**Characteristics of the population**

| Characteristic | N=11,687 |
|---|---|
| Maternal age (y) | 28.6±5.8 |
| Prepregnancy BMI (kg/m$^2$) | 26.4±6.3 |
| Prepregnancy weight (kg) | 69.5±17.3 |
| Height (cm) | 162.2±7.6 |
| Arrest disorder indication for previous cesarean delivery | 3984 (34.1) |
| Obstetrical history | |
| No previous vaginal delivery | 6068 (54.4) |
| Previous vaginal delivery only before previous cesarean delivery | 1456 (13.0) |
| Previous VBAC | 3636 (32.6) |
| Maximum birthweight of previous child (g) | 3405±635 |
| Pregestational diabetes mellitus | 91 (0.8) |
| Asthma | 842 (7.2) |
| History of thyroid disease | 291 (2.5) |
| History of seizure disorder | 91 (0.8) |
| Treated chronic hypertension | 144 (1.2) |
| History of renal disease | 70 (0.6) |
| History of heart disease | 129 (1.1) |
| History of connective tissue disorder | 50 (0.4) |

Data are presented as mean±standard deviation or number (percentage). Number of missing values: prepregnancy BMI (n=3809), prepregnancy weight (n=3591), height (n=531), obstetrical history (n=527), birthweight of previous child (n=824).

*BMI*, body mass index; *VBAC*, vaginal birth after cesarean delivery.

*Grobman et al. Prediction of vaginal birth after cesarean delivery. Am J Obstet Gynecol 2021.*

For each factor in the model, the associations with VBAC were reported as adjusted odds ratios (with corresponding 95% CI). The ability of the model to accurately predict VBAC was assessed using the concordance index, which is a measure that is the equivalent of the area under the receiver operating characteristic curve (AUC).

To describe the probability of VBAC across several characteristics that were significant in the final model, probabilities for combinations of characteristics that were frequent in the cohort were calculated. For each scenario, the percent probability and Wald test–based CIs of VBAC were estimated.

No imputation for missing values was performed. Statistical analyses were performed using the Statistical Analysis System software (version 9.4; SAS Institute, Cary, NC).

## Results

Of the 11,687 individuals (Figure 1) who met the inclusion criteria for this secondary analysis, 8636 (74%) experienced VBAC. The characteristics of the cohort are presented in Table 1. As illustrated, they were diverse concerning their demographic characteristics and their medical and obstetrical history. In addition, they were diverse concerning their reported race and ethnicity: 4239 (36.3%) non-Hispanic Black, 4528 (38.7%) non-Hispanic White, 2325 (19.9%) Hispanic, 227 (1.9%) Asian, and 368 (3.1%) other.

The backward elimination variable selection applied to the training set yielded a model (AUC, 0.76; 95% CI, 0.74–0.78) (Table 2) that included maternal age, prepregnancy weight, height, indication for previous cesarean delivery, obstetrical history, and treated

**TABLE 2**
**Adjusted odds ratios and 95% confidence intervals of factors associated with vaginal birth after cesarean delivery**

| Variable | Training set (n=5741)[a] aOR (95% CI) | Test (validation) set (n=5946)[a] aOR (95% CI) | Overall analytical population (n=7712) aOR (95% CI) |
|---|---|---|---|
| Maternal age, per 1-y increase | 0.97 (0.96–0.99) | 0.98 (0.97–1.00) | 0.98 (0.97–0.99) |
| Prepregnancy weight, per 1-kg increase | 0.98 (0.97–0.98) | 0.98 (0.97–0.98) | 0.98 (0.97–0.98) |
| Height, per 1-cm increase | 1.06 (1.05–1.07) | 1.05 (1.04–1.07) | 1.06 (1.05–1.07) |
| Arrest disorder indication for previous cesarean delivery | 0.54 (0.46–0.63) | 0.57 (0.48–0.67) | 0.55 (0.49–0.62) |
| Obstetrical history | | | |
| No previous vaginal delivery | 1.00 (Referent) | 1.00 (Referent) | 1.00 (Referent) |
| Previous vaginal delivery only before previous cesarean delivery | 2.96 (2.27–3.85) | 1.96 (1.54–2.49) | 2.38 (2.00–2.85) |
| Previous VBAC | 6.52 (5.22–8.14) | 6.50 (5.18–8.14) | 6.48 (5.54–7.59) |
| Treated chronic hypertension | 0.37 (0.18–0.74) | 0.38 (0.20–0.75) | 0.38 (0.24–0.61) |

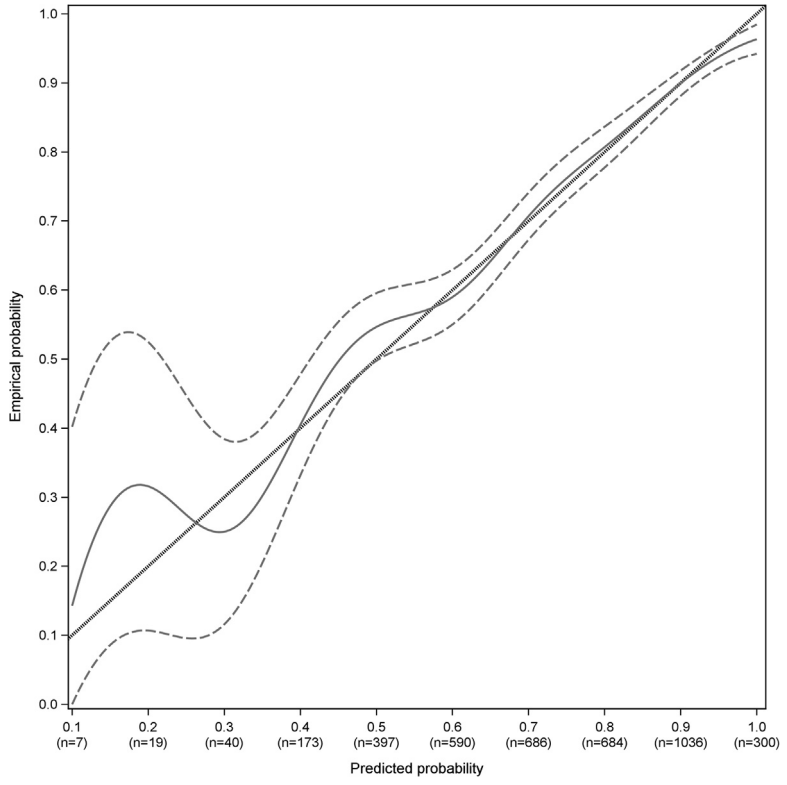
Chance of vaginal birth after cesarean delivery in the analytical group: 73.8%, training set; 74.0%, test set; 73.9%, overall analytical population.

*aOR*, adjusted odds ratio; *CI*, confidence interval; *VBAC*, vaginal birth after cesarean delivery.

[a] n=1961 in the training set and n=2014 in the validation set with missing data for the variables in the final multivariable model.

*Grobman et al. Prediction of vaginal birth after cesarean delivery. Am J Obstet Gynecol 2021.*

**FIGURE 2**
**Calibration curve (with 95% confidence interval) of model validation in the test set**



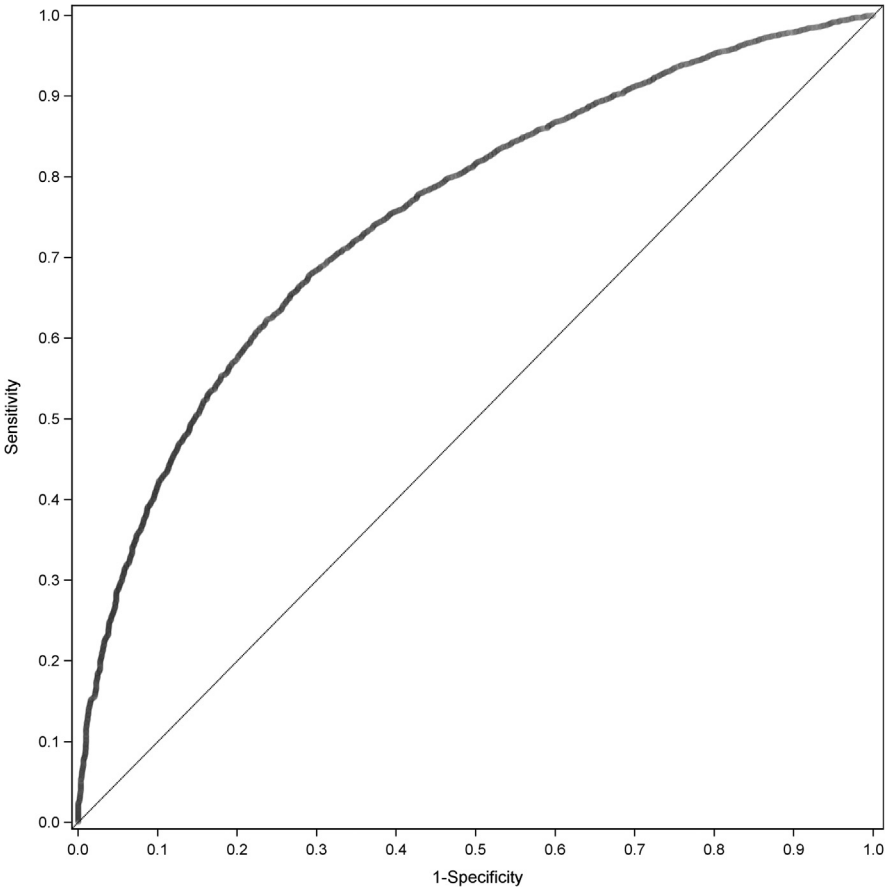

The *dashed straight line* is the line of perfect calibration. The *solid curve* is the calibration curve generated by the prediction model, which is surrounded by *dashed curves* that represent the 95% confidence band of the calibration curve.

*Grobman et al. Prediction of vaginal birth after cesarean delivery. Am J Obstet Gynecol 2021.*

chronic hypertension. VBAC was significantly more likely for women who were taller and had a previous vaginal birth, particularly if that vaginal birth had occurred after the previous cesarean delivery. Conversely, VBAC was significantly less likely among on women whose age was older, whose weight was heavier, whose indication for previous cesarean delivery was an arrest disorder, and who had a history of treated chronic hypertension.

For individuals included in the test (validation) set, the associations of each significant factor with VBAC were similar to the associations with VBAC among individuals in the training set (Table 2), and the corresponding AUC (0.75; 95% CI, 0.73–0.76) was also similar. The related calibration results with the estimated curve and its 95% confidence band confirmed that the predicted probabilities for VBAC were consistent with the empirical probabilities (Figure 2). As illustrated, the predicted probability of VBAC largely adhered to the observed probability of VBAC, with narrow CIs, along a large range of predicted probability values, and only begins to deviate to any degree when the chance of VBAC is <40% (at which point there are very few individuals with such probabilities).

**FIGURE 3**
**Receiver operating characteristic curve of the prediction model**




ROC for vaginal birth after cesarean delivery based on the overall analytical population.

*ROC*, receiver operating characteristic curve.

*Grobman et al. Prediction of vaginal birth after cesarean delivery. Am J Obstet Gynecol 2021.*

Using all individuals in the analytical cohort, the regression was as follows: predicted probability of VBAC = (exp(w)/[1+exp(w)])×100, where w=−5.952−0.023 (age)−0.024 (pre-pregnancy weight, kg)+0.056 (height, cm)−0.597 (arrest indication)+0.868 (previous vaginal delivery only before prior cesarean)+1.869 (previous VBAC)−0.966 (treated chronic hypertension) and with arrest indication, previous vaginal delivery only before previous cesarean delivery, previous VBAC, and treated chronic hypertension coded as 0 for "no" and 1 for "yes." This final equation yielded the odds ratios (95% CI) that are shown in Table 2, and an AUC of 0.75 (95% CI, 0.74−0.77) (Figure 3). The proportion of individuals who had a VBAC in the final analytical cohort (ie, only individuals without missing values for all final variables in the model) and among those with missing data for the final variables in the model was not significantly different (5699 of 7712 [74%] vs 2937 of 3975 [74%]; *P*=.99).

Table 3 shows the predicted probabilities of VBAC, based on the final model in the overall analytical population, for 12 different scenarios for several individuals with different characteristics ascertainable at an initial prenatal visit. As illustrated, depending on the combination of these characteristics, the predicted chance of VBAC varied widely. A web-based calculator, derived from the final regression equation, that generates individualized results, such as those provided in Table 3, is available at https://mfmunetwork.bsc.gwu.edu/web/mfmunetwork/vaginal-birth-after-cesarean-calculator.

## Discussion

### Principal findings

In this analysis, we have developed a model that estimates the probability of a VBAC if an individual chooses to have a TOLAC. In contrast to a previous model based on MFMU data that incorporated the race and ethnicity variables,[10] this model was evaluated without the inclusion of race, ethnicity, or other socially defined constructs.

### Results in the context of what is known

We have shown that we can develop a model that is quite similar in terms of its input variables using the same data source and methodologic approach; in fact, all variables in the previous model were retained, with 1 additional variable (chronic hypertension) identified. The classification ability of the new model is similar to that of the previous model (AUC of 0.75 for both), and it demonstrates excellent calibration across a large range of predicted VBAC estimates. The calibration curve, even more so than the AUC, gives particular insight into the potential value of a model that is designed to provide individual probability estimates to assist with decision making.[21]

### Clinical implications

There is a strong theoretical underpinning for believing that the estimate provided by such a model would be of value to individuals considering whether undergoing a TOLAC is the approach that is best for them. For some individuals, the desire to undertake a TOLAC is informed by the likelihood that it will result in vaginal birth and the strength of their preference for that outcome.[22] Because most maternal and perinatal morbidities in the setting of TOLAC occur in individuals who ultimately have a cesarean delivery[23] and because the chance of morbidity is highly related to the probability of VBAC,[24] this estimation can be also informative regarding other important health outcomes. From a person-

**TABLE 3**
**Predicted probabilities for vaginal birth after cesarean delivery for 12 hypothetical individuals**

| Example | Maternal age (y) | Prepregnancy weight (kg) | Height (cm) | Arrest disorder indication for previous cesarean delivery | Previous vaginal delivery | Chronic hypertension | Predicted probability of VBAC (95% CI) |
|---|---|---|---|---|---|---|---|
| 1 | 30 | 71 | 171 | No | Previous VBAC | No | 95.6 (94.9–96.3) |
| 2 | 30 | 71 | 156 | No | Previous VBAC | No | 90.5 (89.0–91.7) |
| 3 | 30 | 71 | 156 | No | Previous vaginal delivery only before previous cesarean delivery | No | 77.7 (74.7–80.5) |
| 4 | 30 | 71 | 171 | No | No | No | 77.2 (75.2–79.0) |
| 5 | 30 | 44 | 156 | No | No | No | 73.4 (71.1–75.6) |
| 6 | 23 | 71 | 156 | No | No | No | 63.3 (60.8–65.8) |
| 7 | 30 | 71 | 156 | No | No | No | 59.4 (57.0–61.8) |
| 8 | 37 | 71 | 156 | No | No | No | 55.4 (52.1–58.7) |
| 9 | 23 | 71 | 156 | Yes | No | No | 48.7 (46.0–51.4) |
| 10 | 30 | 71 | 156 | Yes | No | No | 44.6 (42.2–47.1) |
| 11 | 30 | 71 | 156 | No | No | Yes | 35.8 (25.6–47.4) |
| 12 | 37 | 71 | 156 | No | No | Yes | 32.1 (22.6–43.5) |

Data are based on the overall analytical population.

*CI*, confidence interval; *VBAC*, vaginal birth after cesarean delivery.

*Grobman et al. Prediction of vaginal birth after cesarean delivery. Am J Obstet Gynecol 2021.*

centered standpoint, an estimation that is personalized vs a population mean should be preferable.

## Research implications

Regardless of the test characteristics of this model, it can only potentially serve its intended purpose of enhancing person-centered care if it is understood and used appropriately. This model was designed to estimate the chance of a clinical event and not a physiological standard; thus, it was not designed to demonstrate inherent or inevitable associations between particular factors and the chance of VBAC. If obstetrical care patterns were to change or vary significantly such that the chance of VBAC after a TOLAC was to also differ, a different model would need to be developed to retain accuracy. In addition, this model was not designed to uncover individual factors or produce a summary probability estimate that indicates someone should or should not undergo a TOLAC. This model was designed to provide an estimate of the chance of VBAC that can be used by people and their providers to assist in an informed and person-centered decision making process.

## Strengths and limitations

One strength of this analysis was that the data were derived by trained and certified research staff, which increased the range of available fields and the accuracy of their ascertainment. In addition, the data came from multiple centers and a diverse population, thereby increasing its generalizability. The method of model development incorporated best practices, such as consideration of nonlinear effects and the use of internal validation techniques. It should be noted that this model was derived from data collected nearly 2 decades ago. However, it was considered an imperative component of our approach to utilize the same dataset and methodologic approach used to develop the previous VBAC prediction model. That model had been used and validated in multiple different settings, and the main purpose of this analysis was to determine whether a model with similar test characteristics could be produced after race and ethnicity were removed from consideration. The newly derived model is very similar to the previous one, with almost identical input variables; the only substantive difference is the absence of race and ethnicity and the addition of chronic hypertension treated with medication, which is a condition that is associated with later obstetrical complications (such as superimposed preeclampsia) associated with failed TOLAC.[25] Moreover, despite the years that have passed, the overall chance that VBAC occurs once a TOLAC is undertaken has remained remarkably stable,[20,26,27] and there is no evidence that the marginal associations of each variable with VBAC have changed over time; thus, there is reason to believe that this model will continue to be relevant to modern obstetrical care.

## Conclusions

The removal of race and ethnicity from the model should serve to reinforce the importance of continually rethinking past approaches to care and striving to achieve equity, without which there would be no person-centeredness or quality. In that regard, it is important to note that there continue to be

disparities in the cesarean delivery rate among individuals who are in labor, with those who identify as Black or Hispanic having higher rates than those who identify as non-Hispanic White,[28,29] and it is of crucial importance to target the social determinants that underlie those differences and eliminate the disparity and related morbidity that result from to it. ■

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