OBSTETRICS

Assessing first-stage labor progression and its relationship to complications

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BACKGROUND: New labor curves have challenged the traditional understanding of the general pattern of dilation and descent in labor. They also revealed wide variation in the time to advance in dilation. An interval of arrest such as 4 hours did not fall beyond normal limits until dilation had reached 6 cm. Thus, the American College of Obstetricians and Gynecologists/Society for Maternal—Fetal Medicine first-stage arrest criteria, based in part on these findings, are applicable only in late labor. The wide range of time to dilate is unavoidable because cervical dilation has neither a precise nor direct relationship to time. Newer statistical techniques (multifactorial models) can improve precision by incorporating several factors that are related directly to labor progress. At each examination, the calculations adapt to the mother's current labor conditions. They produce a quantitative assessment that is expressed in percentiles. Low percentiles indicate potentially problematic labor progression.

OBJECTIVE: The purpose of this study was to assess the relationship between first-stage labor progress- and labor-related complications with the use of 2 different assessment methods. The first method was based on arrest of dilation definitions. The other method used percentile rankings of dilation or station based on adaptive multifactorial models.

STUDY DESIGN: We included all 4703 cephalic-presenting, term, singleton births with electronic fetal monitoring and cord gases at 2 academic community referral hospitals in 2012 and 2013. We assessed electronic data for route of delivery, all dilation and station examinations, newborn infant status, electronic fetal monitoring tracings, and cord blood gases. The labor-related complication groups included 272 women with cesarean delivery for first-stage arrest, 558 with cesarean delivery for fetal heart rate concerns, 178 with obstetric hemorrhage, and 237 with neonatal depression, which left 3004 women in the spontaneous vaginal birth group. Receiver operating characteristic curves were constructed for each assessment method by measurement of the sensitivity for each complication vs the false-positive rate in the normal reference group.

RESULTS: The duration of arrest at $\geq$6 cm dilation showed poor levels of discrimination for the cesarean delivery interventions (area under the curve, 0.55—0.65; $P < .01$) and no significant relationship to hemorrhage or neonatal depression. The dilation and station percentiles showed high discrimination for the cesarean delivery—related outcomes (area under the curve, 0.78—0.93; $P < .01$) and low discrimination for the clinical outcomes of hemorrhage and neonatal depression (area under the curve, 0.58—0.61; $P < .01$).

CONCLUSIONS: Duration of arrest of dilation at $\geq$6 cm showed little or no discrimination for any of the complications. In comparison, percentile rankings that were based on the adaptive multifactorial models showed much higher discrimination for cesarean delivery interventions and better, but low discrimination for hemorrhage. Adaptive multifactorial models present a different method to assess labor progress. Rather than "pass/fail" criteria that are applicable only to dilation in late labor, they produce percentile rankings, assess 2 essential processes for vaginal birth (dilation and descent), and can be applied from 3 cm onward. Given the limitations of labor-progress assessment based solely on the passage of time and because of the extreme variation in decision-making for cesarean delivery for labor disorders, the types of mathematic analyses that are described in this article are logical and promising steps to help standardize labor assessment.

Key words: arrest, descent, arrest of dilation, cesarean delivery, first stage of labor, labor-progress disorder

S ince the landmark publications of Friedman and others[1-6] to quantify labor progress over time, clinicians have used "normal" labor curves to help identify "abnormal" labor. More recently, the publication of several contemporary labor curves that were based on data with current management and interventions has renewed interest in the evaluation of labor progress and contributed to new definitions of arrest disorders.[7-16] The observed range of time to advance 1 cm in dilation or station was very long in normal labor, especially when dilation was <6 cm or station was less than +2.[9-16] Therefore, it was only late in the first stage that an arrest of dilation that lasted 4 hours fell beyond the 95th percentile that is seen in normal labor.

The wide range of time to dilate is not surprising because cervical dilation has neither a precise nor direct relationship to time. Cervical dilation is a direct response to contractions and that response is modified by many others factors, such as pelvic size and shape or biomechanical factors like cervical compliance and occiput position. Furthermore, most of these factors change over time. Consequently, it is inevitable that the relationship of dilation or descent to time will show wide variation, especially in early labor when contractions and cervical compliance can be very different among mothers. Even the current first-stage arrest definitions, which are applicable only at $\geq$6 cm dilation when many of the influential factors listed earlier have reached a stable state, require extra

criteria based on Montevideo units to account for the influence of different contraction patterns.[7,8]

Fortunately, there is a broad base of mathematical modeling techniques that can be applied to the problem of the assessment a process with multiple determinants that evolve over time. A stimulus-response function is a mathematical equation that describes the quantitative response to a measured stimulus. Stimulus-response functions in physiology are complex because there are often many factors that influence the response and because the factors are in constant flux. Statistical models are necessary because the response will cover a range because of natural biologic variation, the effect of measurement inaccuracy, and the effect of unmeasured factors.

An adaptive multifactorial model of dilation in response to contractions was developed previously, and the range of variation in the response appeared adequate for clinical utility.[17] Because station has a defined relationship to dilation, it is possible to use that information to estimate expected station at specific points during the first stage of labor.[18] Using these models, one can construct "expected" dilation and station curves for an individual mother. A mother's actual dilation and station can then be compared with the "expected" ranges and described in percentiles. Percentile ranking are understood easily in clinical medicine; in this application, percentiles summarize the effect of many factors succinctly in a single number. Low percentiles indicate lower than expected dilation and station, taking in to account all the factors in the model including contractions and effacement.

The objective of this study was to assess the relationship between first-stage labor progress and labor-related complications with the use of 2 different labor assessment methods. The first assessment method was based on the first-stage arrest definitions published by the American College of Obstetricians and Gynecologists and the Society for Maternal−Fetal Medicine in 2012.[7,8] The second method used percentile ranking of dilation and station, based on adaptive multifactorial models. We selected 4 labor-related complications. Two complications were related to intervention: cesarean delivery (CD) for first-stage arrest without fetal heart rate concerns and CD for fetal heart rate concerns. Two complications were actual clinical conditions: obstetric hemorrhage and neonatal depression.

Materials and Methods

We included all deliveries with singleton cephalic presentations at ≥37 weeks gestational age that occurred between January 1, 2012, and December 31, 2013, at 2 acute care academic community hospitals and regional referral centers in the Baltimore-Washington corridor. Both spontaneous and induced labors were included. All cases included patients who had electronic fetal monitoring (EFM) for a least 1 hour before birth and umbilical artery gases measured at birth. Mothers with a previous cesarean birth were excluded. De-identified data were extracted from the departmental electronic perinatal database for the clinical variables, from the laboratory database for the paired cord blood gases and from the EFM archiving system for digital versions of the tracings. Clinical examination data was obtained by clinicians with different levels of experience using standard digital vaginal exam techniques. No specific protocols dictated precise clinical management with respect to CD for labor disorders although arrest of dilation was widely accepted to require at least 2 hours or arrest of dilation in the active phase of labor. This approach allows observation of actual practice rather than practice based on a prospective protocol.

Selecting a marker of abnormal labor progression is challenging because intervention is generally performed to prevent complications, such as fetal or maternal trauma. Prevention has a paradoxic effect; it hinders us from seeing the potential adverse outcome. Moreover, there is no postoperative test to always confirm that a labor-progress complication was truly impending. An experiment in which labor is allowed to take its natural course without intervention is both impractical and unethical. To address these limitations, we choose 4 different outcome markers. Two outcomes were related to the decision for CD intervention, and 2 outcomes were objective patient conditions.

CD for a first-stage labor-progress disorder included all women with a cesarean birth before 10-cm dilation where any of the listed indications included a reference to a disorder of labor progress and there were no references to concerning fetal heart rate patterns, abruption, or cord prolapse.

CD for fetal heart rate concerns included all women with a CD in which any of the listed indications included reference to concerning fetal heart rate patterns or abruption or cord prolapse. The 2 CD outcome groups were mutually exclusive.

The neonatal depression outcome included all babies with any 1 of the following events: umbilical artery base deficit >12 mmol/L or intubation or cardiopulmonary resuscitation in the delivery room. We chose to focus on base deficit because it does indicate that the baby had an exposure to hypoxemia and because it does not fluctuate as rapidly as pH. A pH value alone could represent recent respiratory acidosis developing at the end of the second stage.

Recognizing that there are different definitions of postpartum hemorrhage, *obstetric hemorrhage* was defined as an estimated blood loss of >500 mL with a vaginal delivery or >1000 mL with CD. These values corresponded to the 95th percentiles of estimated blood loss recorded with vaginal and CD births in these institutions and are consistent with the definition of postpartum hemorrhage provided in the most recent American College of Obstetricians and Gynecologists practice bulletin on postpartum hemorrhage.[19]

The normal reference group included spontaneous vaginal births without neonatal depression or obstetric hemorrhage. Separate analyses were conducted for nulliparous and multiparous mothers.

First-stage labor disorders develop during labor and become increasingly apparent over time. The clinical decision to intervene generally is finalized at the time of the last examination in the first

stage. Therefore, we noted dilation, duration of arrest of dilation, the percentile ranking of dilation, and station at the last examination of the first stage. These observations were used to construct receiver operating characteristic (ROC) curves and measure the area under the curve (AUC).

ROC curves were constructed by measuring the sensitivity in each of the complication groups vs the false-positive rate in the normal reference group at varying levels of percentiles or the duration of arrest at ≥6 cm dilation.

Dilation percentile rankings were calculated with a stimulus-response model of cervical dilation. This multifactorial model estimates expected cervical dilation and the 5th to 95th percentile range, based on the variables in its equation. The 5 variables are contraction counts (estimated automatically), dilation, effacement and station at the previous examination (from clinical examinations), and the presence or absence of epidural anesthesia. Calculations are updated at each examination, which allowed the curve to adapt to changing conditions. Nulliparous and multiparous mothers have different equations. These stimulus response models for dilation have been cleared by the Food and Drug Administration for clinical use.[20,21] The models were developed with the use of longitudinal statistical techniques for unbalanced repeated measures. The development data set included 7731 examinations from 1341 women with uncomplicated spontaneous vaginal deliveries in 3 different hospitals. In addition, they have been tested prospectively and retrospectively.[22,23] The general structure of the model is shown given:

$$Dilation_t = \omega + \alpha\, Contractions_t$$
$$+ \beta Dilation_{t-1}$$
$$+ \gamma Effacement_{t-1}$$
$$- \vartheta Station_{t-1}$$
$$+ \varphi Epidural_t \pm range$$

Basically, this model states that the expected dilation at a specific time is dependent on the cumulative uterine activity that has been observed since the first examination and that this response is modified according to dilation, station, and effacement at the previous examination and that it is modified also by the presence or absence of epidural anesthesia. The statistical modeling process also estimates the model parameters (the Greek letters of the equation) so that the expected dilation and its range at any time can be calculated when the variables in the model are known. Repeating the calculations at the time of each pelvic examination allows the model to adapt to changing conditions of the variables.

More recently, we have described the relationship between dilation and station in normal labor.[18] By so determining this relationship, it is possible to estimate expected station at various points during the first stage of labor. The station percentiles were calculated based on expected station.

Assessments of labor with the use of the mathematical models are illustrated with 2 examples in Figure 1. Each vertical panel describes a single nulliparous labor. The top graph in each panel in shows the standard graphical display of dilation in red and station in green vs time. The horizontal axis spans 21 hours. Expected dilation and its 5th to 95th percentile ranges are shown by the pale red bands appearing in the middle graphs. Expected station and its 5th to 95th percentile range are shown by the pale green bands in the lowest graph. The first vertical panel shows labor progression with dilation and station advancing in a fashion very similar to the average Zhang curves. The second panel shows a labor with arrest of dilation at 5 cm for 5.7 hours and no advance in station for 11.2 hours. The last dilation and station are below the 1st percentile. Although these examples are all from nulliparous mothers and the graphs use the same equations, the pale red and green bands are different because they are adapting at each examination to her particular combination of values for the five factors in the equation.

Categoric variables were compared with the use of the chi-square test or Fisher's exact test, as appropriate. Continuous variables were assessed for normality with the D'Agostino and Pearson and Kolmogorov−Smirnov test. Variables that were not normally distributed were compared with the use of the Mann-Whitney test, and normally distributed variables were compared with the use of the Student t test. All tests were 2-tailed, and a probability value of <.01 was considered to be significant. The ROC curves and all statistical analysis were performed using GraphPad Prism software (version 5.03 for Windows; GraphPad Software, San Diego, CA).

This study was reviewed and given exempt status by the MedStar Research Institute.

Results

The study sample consisted of all 4703 births. General characteristics of the study groups are summarized in Table 1. The AUCs for each of the ROC analyses are shown in Table 2.

Duration of arrest at ≥6 cm dilation showed statistically significant discrimination for the CD-related outcomes, but the absolute values of the AUCs were low (0.55−0.65). The AUCs for duration of arrest at ≥6 cm dilation and for obstetric hemorrhage or neonatal depression were 0.52 and not statistically significant.

Arrest of dilation for any duration at ≥6 cm dilation was uncommon; it occurred in 3.5% of nulliparous women (47/1341) with spontaneous vaginal births and in only 30.6% in nulliparous women (73/238) with a CD for a first-stage labor disorder. Consequently, the ROC curve for duration of arrest cannot rise above this point (Figure 2).

Dilation percentiles showed excellent discrimination for the CD-related outcomes with high AUCs (0.81−0.93) and statistically significant but low discrimination for obstetric hemorrhage or neonatal depression with very low AUCs (0.60−0.61).

Station percentiles showed very good discrimination for the CD-related outcomes with good AUC values (0.78−0.82) and statistically significant

FIGURE 1
Labor curves from 2 nulliparous women
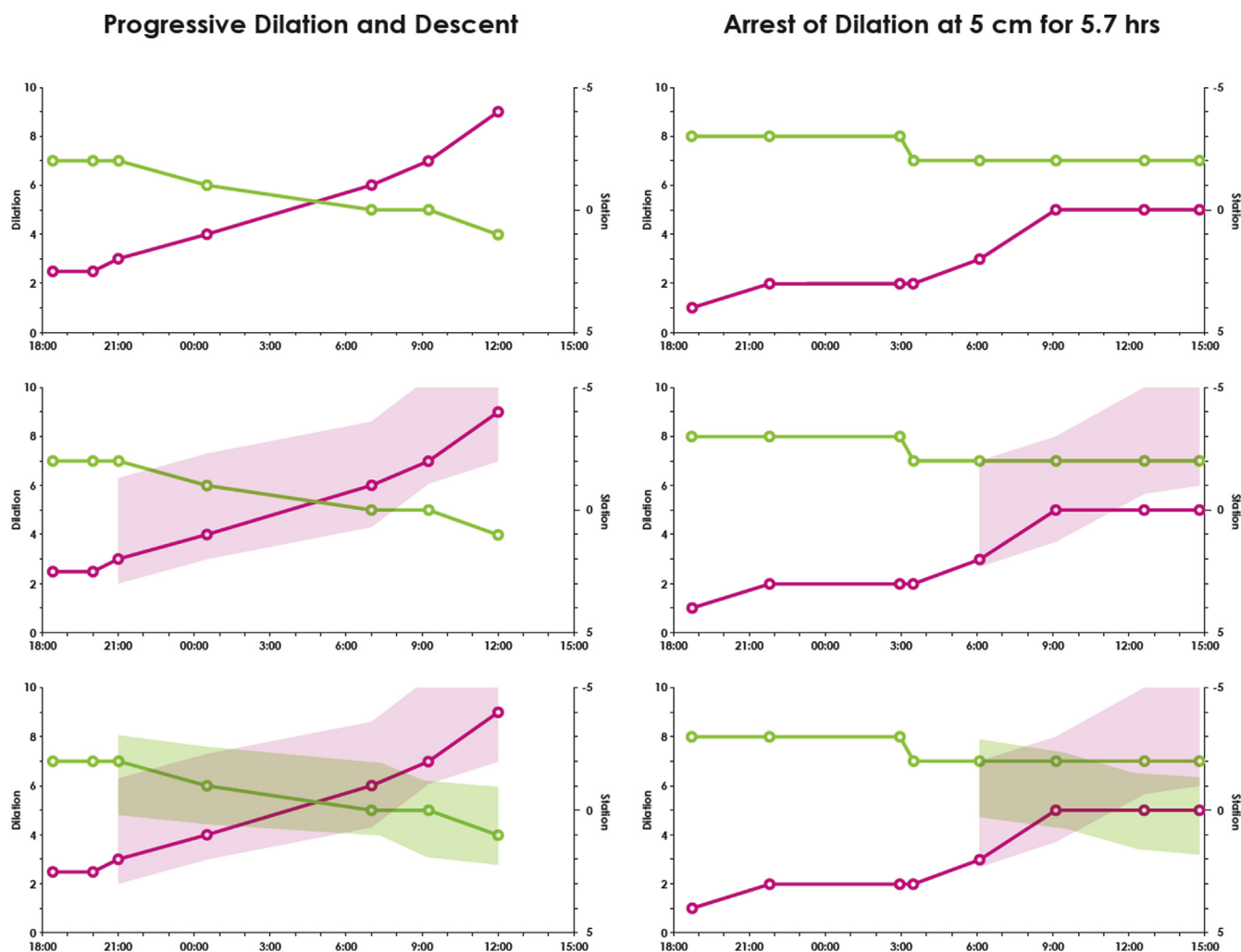
Dilation and station plotted over time in 2 clinical scenarios. The superimposed pale red and green bands represent the 5th-95th percentile ranges of expected dilation and station, respectively. The *thin red line* represents observed dilation; the *thin green line* represents observed station; the *thick red line* represents 5th to 95th percentile range of dilation; the *thick green line* represents 5th-95th percentile range of station.

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but minimal discrimination for obstetric hemorrhage or neonatal depression with low AUCs (0.58—0.61).

The AUC values for dilation percentile and for station percentile were significantly higher than the corresponding AUC values for the duration of arrest in 7 of the 8 pairs of comparisons.

Subanalysis for nulliparous and multiparous women showed very similar results.

Although AUC values provide a good measure of the potential performance of a diagnostic test, they can be difficult to

interpret because clinicians generally would operate at specific intervention thresholds. Therefore, it is useful to measure performance at clinically relevant points. Figure 2 shows the actual ROC curves for the 3 assessment methods for the outcome of first-stage CD for a labor-progress disorder in nulliparous women. The flags indicate the sensitivities, false positive rates, and likelihood ratios for 3 specific points on the curves. During the limited range for which the duration of arrest ROC curve can be completed, its position is inferior

to the ROC curve for dilation percentile and superior to the ROC curve for station percentile.

Comment
Principal findings
The first major finding of this study was that duration of arrest of dilation at ≥ 6 cm dilation showed little or no discrimination for any of the selected outcomes. When duration of arrest was allowed to vary, the ROC curve for duration of arrest at ≥ 6 cm dilation showed low levels of discrimination for

CD for a first-stage labor-progress disorder (AUC, 0.65), minimal discrimination for CD for fetal heart rate concerns (AUC, 0.55), and no discrimination for obstetric hemorrhage or neonatal depression.

In contrast, the use of an adaptive multifactorial statistical method showed substantially more relationship to the complications that are related to poor labor progress. The dilation and station percentiles that were produced by this method showed high discrimination for the cesarean-related outcomes (AUC, 0.78—0.93) and low discrimination for the clinical outcomes of obstetric hemorrhage and neonatal depression (AUC, 0.58—0.61).

Clinical implications

This study has clinical implications in that it presents a different method to assess dilation and descent in labor. The shapes of the new labor curves have challenged the traditional understanding of phases and rates of dilation and descent in labor.[9-17] Their wide ranges of variation highlight the limitations of the use of time alone to evaluate labor progress.

The adaptive multifactorial models presented here incorporate several explanatory factors that are related directly to labor progress. Rather than a "pass/fail" assessment that is applicable only in late labor, the models allow for a continuous quantitative assessment of progress with the use of percentile ranking, where calculations can adapt at each examination to the mother's current labor conditions. The calculations can be applied from 3 cm onward and can assess 2 essential processes for vaginal birth: dilation and descent.

Research implications

Many questions remain to be researched. Percentile criteria to define clinical abnormality are not established. A specific percentile ranking from a healthy population does not necessarily equate to a diagnosis of clinical abnormality. By definition, 5% of a healthy population will fall below the 5th percentile. Nevertheless, as a general principle in medicine, a large deviation

from the normal range that is seen in a healthy population often suggests the presence of disease or at least an increased risk for illness. An experiment where labor is allowed to take its natural course without intervention to determine safe limits is impossible and unethical. However, with access to large amounts of electronic data, it will be possible to examine rare outcomes like

birth-related trauma and their relationship to labor progression.

Strengths and limitations

There are limitations in the selection of labor-related complications. None of the outcome markers are perfect. Having a CD for a labor-progress disorder reflects a clinical decision and is not identical to having a confirmed clinical condition


TABLE 1
Characteristics of the study population

Variable	Measure
Characteristic, n (%)	
Nulliparity	2671 (56.8)
Multiparity	2032 (43.2)
Diabetes mellitus	232 (4.9)
Hypertension	601 (12.8)
Induction	1937 (41.2)
Augmentation	1121 (23.8)
Cesarean delivery	1116 (23.7)
Spontaneous vaginal birth	3233 (68.7)
Cesarean delivery for a first-stage labor disorder without fetal heart rate concerns	272 (5.8)
Cesarean delivery for fetal heart rate concerns	558 (11.9)
Obstetric hemorrhage	178 (3.8)
Neonatal depression	237 (5.0)
Median gestational age, wk (interquartile range)	39.7 (38.9—40.4)
Median birthweight, g (interquartile range)	3321 (3037—3629)
Median body mass index, kg/m^2 (interquartile range)	31.5 (27.7—35.4)

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TABLE 2
Area under the curve for the duration of first-stage arrest at ≥6 cm dilation for dilation percentile and for station percentile in each of the outcome groups

Variable	Intervention outcome		Clinical outcome	
	First-stage cesarean delivery for labor-progress disorder	Cesarean delivery for fetal heart rate concern	Obstetric hemorrhage	Neonatal depression
Duration of arrest at ≥ 6 cm dilation	0.65[a]	0.55[a]	0.52	0.52
Dilation percentile	0.93[a,b]	0.81[a,b]	0.60[a]	0.61[a,b]
Station percentile	0.82[a,b]	0.78[a,b]	0.61[a,b]	0.58[a,b]

[a] $P < .01$; [b] $P < .01$ for comparison with duration of arrest.

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FIGURE 2
Receiver operating characteristic curves
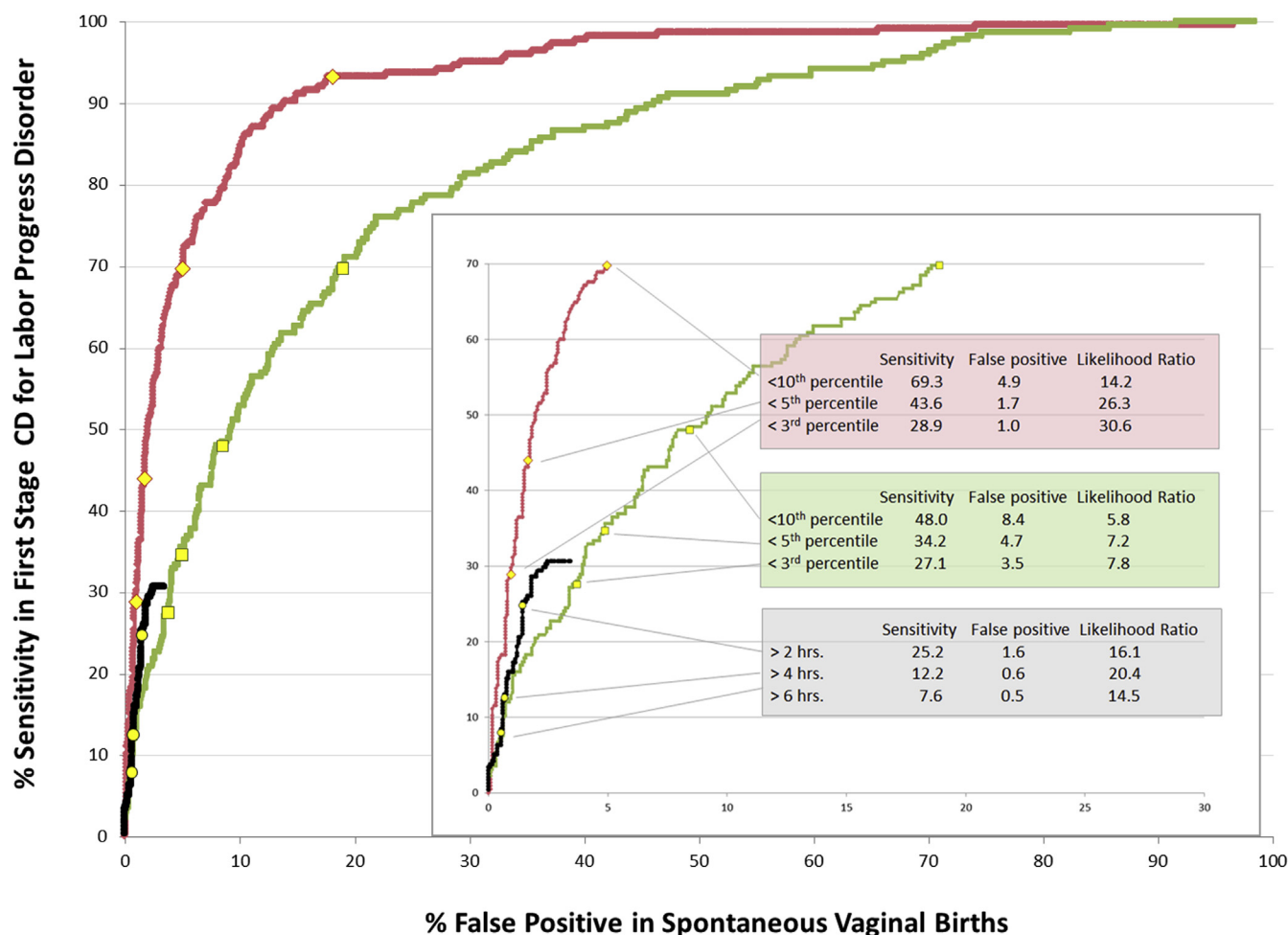
Receiver operating characteristic curves for percentile ranking of dilation, percentile ranking of descent, and duration of arrest of dilation at ≥6 cm in nulliparous women with a cesarean delivery for a first-stage labor disorder vs spontaneous vaginal birth. The *insert* shows sensitivity, false-positive rate, and likelihood ratio at 3 selected points along each curve. The *red line* represents dilation percentile; the *green line* represents station percentile; the *black line* represents the duration of arrest at ≥6 cm dilation.

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and may not reflect a true clinical condition at all in some cases. High blood loss or neonatal depression is caused by many factors and is related only indirectly to long labors. Despite these limitations, labor-progress disorders would be expected to show some relationship to these labor-related conditions or interventions. In addition, each labor assessment method was subjected to the identical imperfect test, making such comparisons valid.

There are limitations with mathematical models. They do require minimal bedside computerization for the computations. They do not consider every factor that influences labor progression. There are a myriad of factors that clinicians integrate when considering labor progression, such as fetal head position, molding, caput, contraction strength, and pelvic shape, to name a few. For these variables to be studied in a multifactorial model development phase, they must be measurable with reasonable precision and available at every examination. Once these criteria are met, the

statistical techniques that are used to select the best combinations of factors will determine whether they add to the model performance significantly while maintaining its robustness. None of these additional factors were recorded with sufficient regularity for inclusion in our original models.

In the future, we expect that multifactorial adaptive models that are related to labor will improve with the incorporation of different explanatory factors, such as head position or pelvic size. In the original development phase

of modeling dilation, we tested the effect of adding membrane status as a variable because there was strong clinical belief that it would be helpful. When we did not include measures of contractions and station, membrane status had an effect. However, when contractions and descent were accounted for, membrane status did not add significantly. That is mathematically the effect of membrane rupture seemed to be mediated through changes in contraction frequency and descent. Incidentally, we often observed an increase in contraction frequency after rupture of the membranes.

In addition, more accurate measurements of dilation and stations and evolving mathematical techniques will improve the models. That said, these multifactorial models in their current state can help reduce inconsistency in the evaluation of dilation and descent. Although a statistical process reduces the subjectivity of the mental adjustments that humans must make for the variables included in the equations, there will always be a need to superimpose clinical judgment because no model will account for all the factors that influence labor in every patient.

There are limitations with this study design. Generalizing these results to other centers must be considered with caution for several reasons. The cesarean delivery rates were higher than the national average. Maryland and Washington, DC, where the data originated, ranked 7th and 9th among all US states for cesarean delivery rates in nulliparous women with singleton term vertex presentations in 2013.[24] Other patient and health care differences can make a particular center different from these centers.

This was a retrospective not a prospective study. Analyses of retrospective data are helpful because they are informative and carry no direct patient risk. Prospective randomized clinical trials in labor management are desirable, but very difficult to conduct. There are a multitude of steps between labor assessments and final outcome. Final outcomes are affected by deficiency at

any step. Better diagnosis of a labor problem will not result in an improvement in outcome if any subsequent action is untimely or ineffective. Thus, any prospective clinical trial will have to ensure that all steps subsequent to diagnosis are completed as per protocol. It is also useful to remember that the effect of a labor assessment method is intended to change the reasoning and behavior of the clinicians who manage labor. Clinicians, or more likely entire centers, would need to be randomized.[25] Otherwise, individual clinicians carry their learning and experience from 1 patient to the next. This transfer of effect causes contamination in a trial in which the unit of randomization is the individual patient. Given the stability of cesarean delivery rates, even with concerted efforts to change them, a "before and after" study design would be informative, once there is greater certainty about the optimal intervention threshold for the percentile based method.

Conclusions

Stimulus-response models are found in a wide range of domains from natural sciences (such as physics and chemistry) to applied sciences (such as structural engineering) and even social sciences (such as economics and political science) in which there are multiple influential factors at play. In obstetrics, the models present a different method to assess labor progress. Rather than "pass/fail" criteria applicable only to dilation in late labor, the models produce percentile rankings, assess 2 essential processes for vaginal birth (dilation and descent), and can be applied from 3 cm onward.

Virtually all scientific endeavors that translate into everyday practice in industry and in many medical fields are now directed by computer-based devices that not only process the type and volume of complex data that are generated during labor but also can give direction as to the subsequent likelihood of adverse outcomes or need for intervention to avoid them. Given the inherent limitations of the use of time to assess

labor and the extreme variation in decision-making for CD for labor disorders, the types of mathematical analyses described in this report are logical and promising steps to help standardize labor assessment.[26] ∎

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