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On prediction of the cesarean delivery risk in a large private practice

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Objective: This study was undertaken to develop an easily usable integrated formula for predicting the probability of cephalopelvic disproportion/failure to progress (CPD) and cesarean delivery (CS) as a function of demographic factors in a middle-class private practice, and to evaluate risk factors for CS in a low-risk primiparous population.

Methods: We studied 3355 primiparous women who delivered singleton births between February 1993 and July 2001 in a large private practice. We calculated body mass index (BMI) and weight gain during pregnancy by using clinical data from a comprehensive clinical database. Multivariable logistic regression analysis was used to estimate the relationship between the probability of CS and CS carried out for CPD and 6 demographic factors: maternal age, maternal height, initial pregnancy BMI, pregnancy weight gain, gestational age, and birth weight. Three methods were used to assess the accuracy of the model: the Hosmer-Lemeshow goodness-of-fit statistic, association of predicted probabilities, and direct comparison of the formula to the actual data. Odds ratios with a 95% CI are also calculated for each of these factors.

Results: The overall rate of primiparous CS for the practice is 21.7%, with 11.7% carried out for CPD. Formulas were developed to predict the probability of CS and the probability of CS caused by CPD. Our analysis shows that both the risk of CS and the risk of CS caused by CPD are significantly associated with all 6 demographic factors. We also develop an easily usable Web page-based calculator to instantly estimate any woman's probability of a CS or CPD at the beginning or at the end of her pregnancy.

Conclusion: The probability of CS and CS performed for CPD is higher for shorter, older, more obese women with large pregnancy weight gains, larger fetal birth weights, and longer gestation ages. Accurate formulas that predict the probabilities of CS and CS performed for CPD in this large private practice have been developed.

The cesarean delivery (CS) rate in the United States is increasing.[1] Further, the demographics[2,3] of the United States are changing in ways that would predict a continued rise in difficult labors and therefore CS.[1,3-6] The determination of an optimal or "appropriate" CS rate has proven difficult if not impossible. It is our opinion

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that such a determination is only possible if there is an accurate mathematical model to describe the "risk" of difficult labor. In addition, we believe the obstetric climate of the 21st century will demand an accurate assessment of any individual's risk of difficult labor before labor. This model must depend on easily measured factors that can be known with certainty or estimated with reasonable accuracy before labor. There are easily measured and very objective demographic factors that can be evaluated in such a way as to allow a reliable statistical prediction of the risk of difficult labor and CS in a low-risk population. We have chosen body mass index (BMI), maternal height, maternal age, pregnancy weight gain, gestational age at delivery, and fetal birth weight. These factors are easily and accurately measured and are entirely objective, with the exception of fetal birth weight, which can only be accurately known after delivery. This prediction can be made at the beginning of pregnancy on the basis of maternal age, BMI, and height. At the end of pregnancy or at the onset of labor, the probability of CS can be calculated again with the addition of the gestational age and estimated fetal birth weight, whereas the maternal weight gain is now a known factor. In this study, we will establish the validity of our statistical predictions by using all 6 factors (age, height, weight, maternal weight gain, gestational age, and birth weight). We will also develop an easily usable Web page-based calculator[7] to instantly estimate any woman's probability of a CS or cephalopelvic disproportion (CPD). There have been other scoring systems, but our formula almost instantly gives any primiparous woman who is at statistical "risk" of CS and CPD and is available at the beginning of pregnancy as well as the onset of labor. In addition, the Web-based calculator is remarkably easy to use. These formulas will allow a statistical evaluation of any primiparous woman who is at "risk" of CS or CPD before labor and a comparison of CS rates in comparable populations.

Material and methods

Previous studies [1,4-6,8,9] and our own large database demonstrate that the rate of CS and CPD is related to age, height, BMI, and pregnancy weight gain. In addition, the CS rate for CPD and for other indications is strongly related to birth weight of the fetus as well as the mother's gestational age.[4,8] Since 1993, Gainesville Women's Physicians and subsequently North Florida Women's Physicians have kept a detailed database on all their obstetric patients. This large database contains information including, but not limited to, each patient's age, height, parity, initial weight, weight gain, BMI at first visit, fetal birth weight, gestational age at delivery, type of delivery, and indications for CS. This practice began with 5 physicians and has added 4 more obstetricians, with 1 retiring. All are board-certified specialists in Obstetrics and Gynecology. There has been a very concerted effort to obtain a level of practice standardization in diagnosis and labor management with periodic clinical meetings to review the statistics and data generated by our database and a review of problem or high-risk cases. Data entry is carried out under the direct supervision of the nursing supervisor. Data are gleaned from the patient's office chart, as well as the Labor and Delivery Record, by the nurse supervisor or Dr Young. These data are entered soon after every delivery. Data entry itself was usually performed by the nursing supervisor but occasionally by clerical personnel under the her supervision or the supervision of Dr Young. There were 7753 deliveries between February 1993 and June 13, 2001. Among these deliveries, there were 3383 primiparous deliveries of different gestational ages, including twin gestations, with 3355 patients delivering singletons and having sufficient data for analysis with respect to all the 6 demographic factors. Maternal age was the age in years at the time of the initial visit for pregnancy care. Maternal heights were primarily self-reported. Weight gain was taken as the difference between the first recorded weight and the last recorded weight in the patients who presented before 20 weeks. The vast majority of patients presented in the first trimester. If the patient registered after the 20th week, a best estimate of prepregnancy weight was made based on her self-reported prepregnancy weight and the initial weight recorded in the office. The first recorded weight or initial weight was used as the basis for the calculation of BMI. Indications for CS in primiparous women were recorded as CPD/failure to progress, fetal distress, breech, and other. The definitions of the various diagnoses have been reviewed at office meetings and as the database was being constructed and refined. Generally, the diagnosis of CPD in a primiparous woman required little or no progress over a 2- to 4-hour period with contractions documented to be adequate and cervix dilated to at least 3 or preferably 4 cm. Over the period of 8 years, the frequency of this diagnosis has been extremely stable over the entire practice.

Frequently CPD/failure to progress was associated with other diagnoses such as fetal distress that might have occurred at the end of a long labor. In these instances CPD was given precedence as an indication. Similarly, there was no attempt to assess the prenatal course and any complications or problems that might cause an increase in the risk of CS, and any assessment of CS morbidity was beyond the scope of this study. Specifically, this study was primarily about a low-risk population and easily measured and objectively accurate demographic measurements such as height, weight, weight gain, calculated BMI, age, birth weight, and gestational age.

Because of the large number of data available, we modeled all 6 factors as continuous independent variables: maternal age in years, maternal height in inches, maternal BMI in kg/m^2, pregnancy weight gain in pounds, gestational age in weeks, and birth weight in grams. In addition, we determined 5 possible interactions between these variables, which are also included in the model. These are maternal age with maternal BMI, maternal BMI with fetal birth weight, maternal BMI with gestational age, pregnancy weight gain with fetal birth weight, and fetal birth weight with gestational age. We evaluated the possibility of multicolinearity by assessing the correlation between each pair of variables. It turned out that the correlation coefficient between each pair of independent variables is less than 0.2. Therefore, multicolinearity should not be a problem. Furthermore, the stepwise selection approach rejects any variables that generate significant multicolinearity. We performed multivariate logistic regression analysis using the SAS software package (SAS, Inc, Cary, NC).[10] The variable selection method used in the logistic regression procedure was chosen to be the stepwise selection method with the acceptance level selected as 0.05. The χ^2 tests were used at each step to test the significance of each factor. The Hosmer-Lemeshow goodness-of-fit statistic was calculated to assess the goodness of fit of the model to the data. The association of predicted probabilities was used to assess the predictive ability of the model. A pair of observations with different responses is said to be concordant if the observation with the response of 1 has the higher predicted event probability. Higher percentages of concordant and lower percentage of discordant indicate a better predictive ability of the model. The results of the regression were used to build an integrated formula for predicting the probability of CS and CS caused by CPD as a function of the 6 demographic factors. Association of each factor with CS was expressed as odds ratio (OR) with 95% CI. Direct comparison between the predicted probabilities on the basis of the recorded demographics and the actual outcomes was also performed to assess the accuracy of the formula.

Results

The demographic features of this population are shown in Table I. The overall rate of primiparous CS for the practice is 21.7%, with 11.7% carried out for CPD.

The notations used in the integrated formulas are as follows: Probability CPD, probability CS, maternal age (MA) (year), maternal height (MH) (inches), pregnancy BMI, weight gain during pregnancy (WG) (pounds), gestational age (GA) (weeks), and fetal birth weight (BW) (grams). Formulas (1) and (2) predict the probability of CPD and overall CS as a function of the 6 demographic factors.

Table I Demographic characteristics (N = 3355)

	N	Total (%)	CS (%)	CPD (%)
Age (y)				
<20	299	8.9	12.96	8.3
20-24	865	25.8	18.82	9.8
25-29	1231	36.7	21.1	10.8
30-34	677	20.2	26.95	14.1
≥35	283	8.4	40.35	23.9
BMI				
<20	546	16.3	12.7	3.99
20-25	1609	48	18.4	9.65
25-30	703	21	24.85	14
30-40	431	12.8	36.9	22.9
>40	66	2	42	24.6
Height (in)				
<62	311	9.3	32.6	21.1
62-64	1291	38.5	22.7	12.5
65-68	1477	44	19.9	9.7
>68	276	8.2	14.9	7.64
Weight gain (lb)				
<25	852	25.4	20.9	11.5
25-35	1383	41.2	19.3	10.1
>35	1120	33.4	25.4	13.8
GA (wk)				
<37	233	6.9	25.	2.9
37	200	6	17.8	5.9
38	458	13.7	21.5	8.1
39	863	25.7	23.4	10.7
40	1040	31	16.9	12
41	495	14.8	25.5	18.3
42	66	2	48.4	43.9
Birth weight (g)				
<2500	138	4.1	33.3	2.17
2500-2999	453	13.5	19.8	5.7
3000-3499	1336	39.8	16.1	7.44
3500-3999	1074	32	22.5	14.6
4000-4499	296	8.8	33.7	26.1
≥4500	58	1.7	63.7	50

GA, Gestational age.

Formula (1) probability (CPD) = Odds(CPD)/(1+ Odds (CPD)), where

$$\text{Odds (CPD)} = \text{EXP}(16.6242 - 0.3803\times\text{GA} + 0.0692\times\text{MA} - 0.2063\times\text{MH}\times 0.0109\times\text{WG} - 0.00545\times\text{BW} + 0.0931\times\text{BMI} + 0.000174\times\text{BW}\times\text{GA})$$

Formula (2) probability (CS) = Odds (CS)/(1 + Odds (CS)),

$$\text{where Odds} = \text{EXP}(26.3663 - 0.7095\times\text{GA} + 0.0811\times\text{MA} - 0.1374\times\text{MH} + 0.0815\times\text{WG} - 0.00719\times\text{BW} + 0.083\times\text{BM} - 0.0000178\times\text{BW}\times\text{WG} + 0.000213\times\text{BW}\times\text{GA})$$

We used 3 different methods to assess the accuracy of these formulas. First, the Hosmer-Lemeshow type of goodness-of-fit tests were performed, both of which resulted in a large *P*-value (.4019 and .3711, respec-

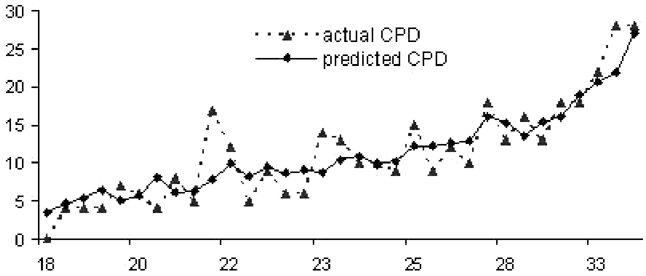

Figure 1 Graph comparing predicted and actual rates of CPD.

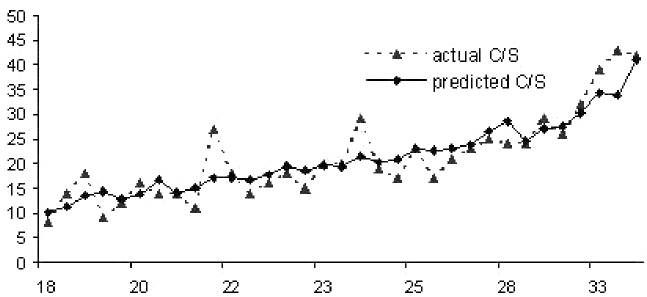

Figure 2 Graph comparing predicted and actual rates of CS.

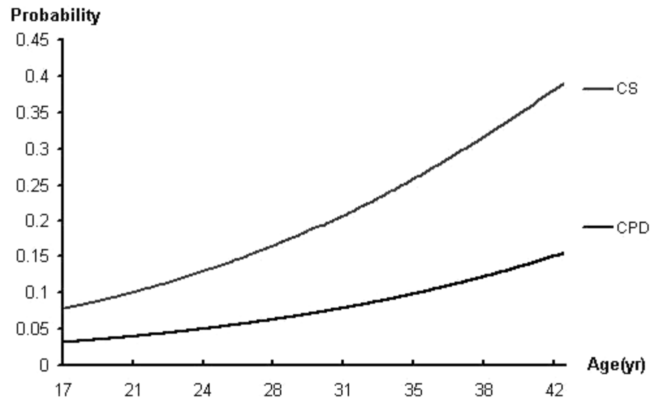

Figure 3 Effect of age with other factors controlled.

Table II Association of predicted probabilities

	CPD prediction formula	CS prediction formula
% Concordant	78.3	69.9
% Discordant	21.3	29.6
% Tied	0.40	0.50

tively), indicating that the null hypothesis for the formulas fit well and the data could not be rejected. The association of predicted probabilities showed high percentages of concordant and low percentages of discordant (Table II), which further verified that the model is a good fit. Moreover, we compare the predicted rates of CPD and CS directly with the actual rates of CPD and CS by constructing Figures 1 and 2. These 2 graphs are constructed as follows: the 3355 data pieces are sorted in the ascending order of their BMI and the first 3300 data sets are separated into 33 distinct groups, each group size of 100. For each group, the predicted and actual total number of CS and CPD are calculated as follows: the predicted total number of CS is calculated by summing up the predicted probabilities of all the data pieces in that group; the actual total number of CS is equal to the actual observed number of CS in that group. The predicted and actual total number of CPD of each group are calculated likewise. We then plot the predicted and actual total number of CS and CPD of each group as shown in Figures 1 and 2. From these figures, we observe that the predicted curves track the actual curves reasonably well. BMI was chosen as the variable to be represented because of its central importance in CPD and CS; however, all other variables were also modeled with similar results.

With the use of formulas (1) and (2), we can easily estimate the risk of CPD and CS. For example, CPD rate and overall CS rate of a 29-year-old primiparous woman who is 63-inches tall with a weight of 132 lb, a pregnancy weight gain of 42 lb, an estimated fetal birth weight of 3700 g, and a gestational age of 41 weeks are 23.8% and 32.7%, respectively. Figures 3 through 8 depict the association of the probability of CPD and overall CS with each 1 of the 6 variables with the other 5 controlled at the median.

Tables III and IV demonstrate the progression of ORs of CPD and overall CS as the 6 factors increase or decrease and with the others held at median. For instance, the first row in Table III states the following: The probability of CS for CPD increases by 22.8% with an increase of 3 years in maternal age if all other demographic factors are held at median. The confidence interval at a $P < .05$ lies between a 15.4% increase and a 30.9% increase.

We noticed that the increase in OR of CPD is associated with a decrease in maternal height, an increase in maternal age, pregnancy BMI, pregnancy weight gain, gestational age, and birth weight. For instance, there is a 5 times increase in OR of CPD when the BMI increases from 15 (lean) to 35 (grade 2 obese). An increase of pregnancy weight gain from 15 lb to 65 lb more than doubles the OR of CPD. The association of the probability of CS is similar to the association of the probability of CPD in all the 6 factors.

Finally, we developed an easy-to-use Web page-based calculator[7] to instantly estimate any woman's probability of a CS or CPD (Figure 9). This calculator can be used to predict the risk of CPD and overall CS at the beginning of pregnancy on the basis of maternal age, BMI, height, and an estimate of pregnancy weight gain.

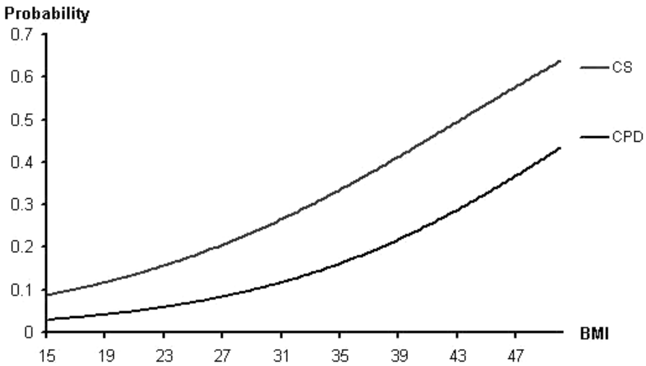

Figure 4 Effect of BMI with other factors controlled.

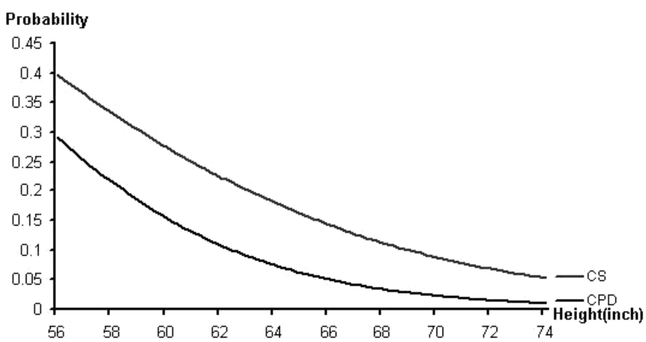

Figure 5 Effect of height with other factors controlled.

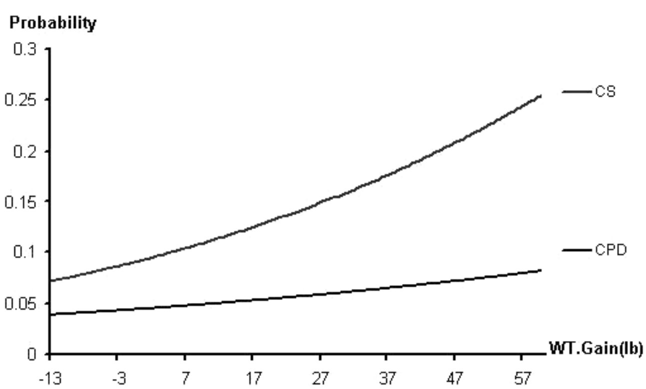

Figure 6 Effect of weight gain with other factors controlled.

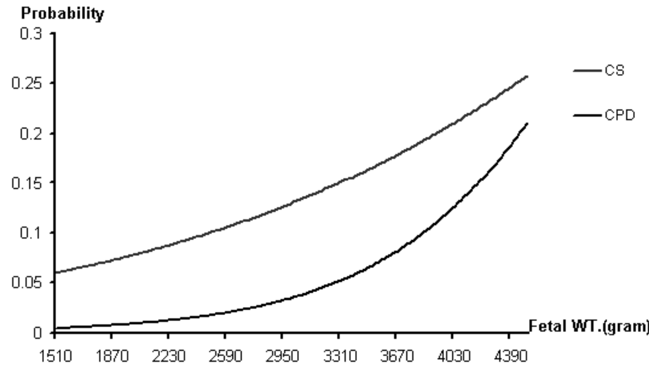

Figure 7 Effect of fetal weight with other factors controlled.

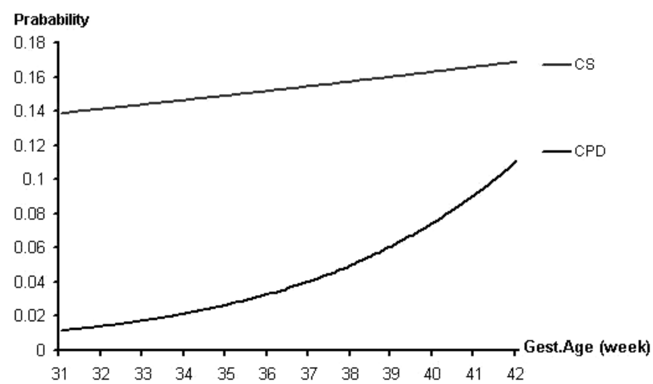

Figure 8 Effect of gestational age with other factors controlled.

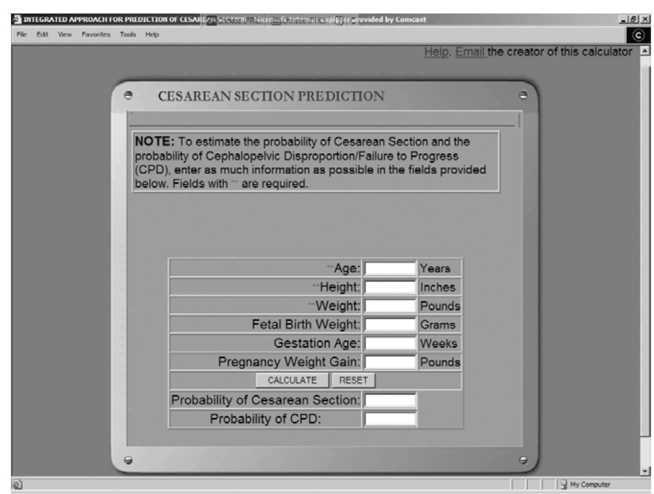

Figure 9 Web-based calculator for predicting CPD and CS.

At the end of pregnancy or at the onset of labor, these risks can be estimated again with the addition of the gestational age and estimated fetal birth weight, whereas the maternal weight gain is now a known factor.

Comment

Our prediction formulas have been shown to be generally accurate for this practice and this time frame. Although we believe it will prove reasonably accurate for other similar practices, additional data will be necessary to determine the formulas' general accuracy and applicability. We look forward to efforts by other practices to corroborate its general accuracy. Nevertheless, we admit that these formulas have limitations. First

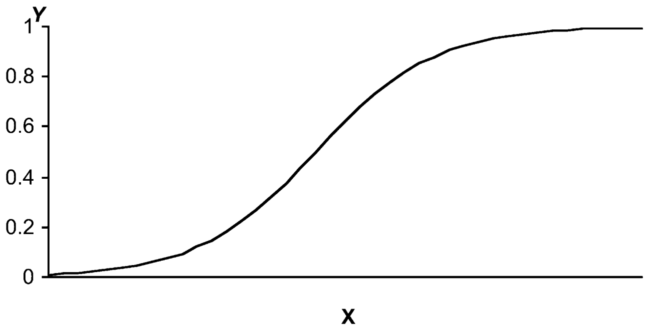

Figure 10 Shape of the logistic function when the predictor variable (*X*) and dependent variable (*Y*) are positively associated.

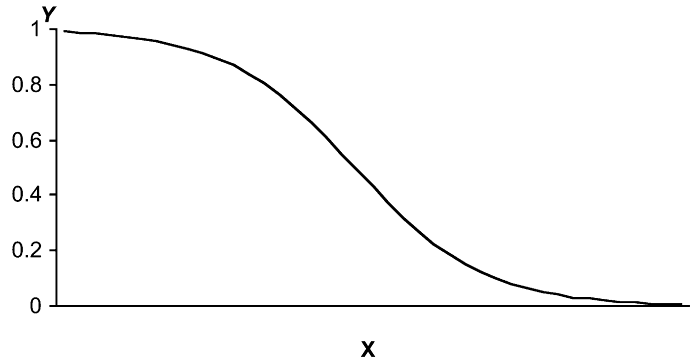

Figure 11 Shape of the logistic function when the predictor variable (*X*) and dependent variable (*Y*) are negatively associated.

Table III Progression of adjusted OR of CPD

Factor	Step size	Progression in OR (CPD)	95% CI
MA	Every 3 y older	1.228	(1.154-1.309)
MH	Every 2 in shorter	1.506	(1.374-1.648)
BMI	Every 3 (kg/m^2) of increase	1.320	(1.246-1.401)
GA	Every 1 wk longer	1.232	(1.113-1.363)
Weight gain during pregnancy	Every 5 lb more	1.057	(1.005-1.110)
Fetal birth weight	Every 250 g more	1.441	(1.389-1.494)

MA, Maternal age; *MH,* maternal height.

Table IV Progression of adjusted OR of CS

Factor	Step size	Progression in OR (CS)	95% CI
MA	Every 3 y older	1.268	(1.237-1.300)
MH	Every 2 in shorter	1.304	(1.260-1.350)
BMI	Every 3 (kg/m^2) of increase	1.290	(1.259-1.321)
GA	Every 1 wk longer	1.073	(1.039-1.109)
Weight gain during pregnancy	Every 5 lb more	1.094	(1.074-1.115)
Fetal birth weight	Every 250 g more	1.133	(1.103-1.164)

of all, both formula (1) and formula (2) are based on the logistic regression model, which has a monotonously increasing or decreasing sigmoid shape in regard to any predictor variable, as illustrated by Figures 10 and 11. The use of the logistic regression model assumes that the (true) association between the risk of CPD or CS and any 1 of the 6 predictor variables can be accurately depicted by some segment of a curve that is similar in shape to those in Figures 10 and 11. Although this is a reasonable assumption when the values of the predictor variables are restricted within certain ranges (as discussed in the previous section and illustrated in Figures 1 through 8), it may not be a valid assumption when the values of the predictor variables are unrestricted or exceptional values are included, for instance, ages less than 17 years or heights greater than 74 inches. Further, the use of the logistic regression and its smooth, sigmoid curve cannot accommodate sudden vertical jumps or drops in the relationship between the risk of CPD or CS and the predictor variables. For example, our formulas significantly underestimate the risks of CPD and CS for primiparous women whose gestational ages reach 42 weeks. This is because patients whose gestational ages go beyond 41 weeks often have a variety of obstetric problems that lead to a sudden increase in both the CPD and CS rate. Similarly, the CS rate is elevated for fetuses less than 37 weeks' gestation and less than 2500g birth weight. This obviously represents a change not predicted by the extended sigmoid curves. Ideally, separate analysis can be carried out to better assess the associations among the risks of CPD and CS and the predictor variables with exceptional values. However, the very limited data that we have for these exceptional cases prohibit such analyses. We recommend that the formulas and the Web page-based calculator presented in this article be used to assess the risks of CPD and CS when the demographics of the primiparous women are within reasonable ranges. In cases in which the primiparous women have exceptional characteristics (for instance, gestational age longer than 41 weeks or shorter than 37 weeks), the formula may not be accurate and will need careful physician input.

This is a sophisticated statistical evaluation of 1 private practice that has a large and consistent obstetric database. The substantial relationships between maternal demographics and CS have been observed by others.[1,3-6,11,12] Scoring systems that include both antepartum and intrapartum factors have been proposed, but to our knowledge, not in a fashion that delivers a specific percentage risk to a specific patient and not with the ease of use inherent in a Web-based calculator.[13,14] We also believe that this study looks at a generally understudied group that makes up the substantial majority of pregnant women in the United States. This group being the low-risk "private practice" patient. The results of this study indicates that a global formula for predicting the "probability" of CS and the risk of difficult labor (CPD/failure to progress) in any primiparous woman, both at the beginning of her pregnancy and before labor, is possible. An easy-to-use Web-based calculator was developed to allow an almost instant prediction of the probability of CS and the effect of changes in weight gain, gestational age, and final birth weight on this probability. Further modification of these formulas would allow a very accurate prediction of overall primiparous CS rate in a given population. This formula may not be quite as accurate for other practices, as the impact of individual physician practice behavior in North Florida Women's Physicians is an integral part of this prediction formula. By the same token, this formula offers a method for comparing physician practice patterns and its effect on CS, and moreover, it demonstrates a method for comparing rates of difficult labor and the risk of CS in different populations. Our efforts to determine an appropriate frequency of labor intervention and CS have foundered on the difficulty in comparing different obstetric populations. In the past we have simply assumed that there are low-risk and high-risk populations and that all low-risk populations are similar. This study would strongly suggest this assumption is incorrect.

In the United States, CS has become the primary tool to manage the risks inherent in labor. In addition, our pregnant population has become significantly older and more frequently obese with increased pregnancy weight gain. This would strongly suggest an increase in difficult labor and CS. Finally, the United States has a difficult tort system that makes the cost of a bad outcome both devastatingly high and capricious. We believe that an accurate mathematical description of the demographic risk of CS will allow an assessment of the real risk of difficult labor as opposed to the perceptions and possible misperceptions of our present medicolegal environment.

In further studies we plan to assess and compare the effect of physician practice behavior on the rate of intervention in general and specifically to various demographic groups that may be at a higher risk of difficult labor. We hope to identify certain situations in which the probability of a successful vaginal delivery is too low to justify a trial of labor. Further, there are data available from Sweden and Europe, which will allow some societal comparisons that might allow a better assessment of the effect of our tort and medical systems on the frequency of obstetric intervention. The transition from an art to a science depends on a mathematical description of reality. We believe this is a first step in that direction.

Conclusion

The risk of CS caused by CPD is higher for shorter, older, more obese women with large pregnancy weight gains, larger fetal birth weights, and longer gestational ages. The total risk of CS is higher for shorter, older, more obese women with large pregnancy weight gains, larger fetal birth weights, and shorter gestational ages. An accurate formula that predicts the probabilities of CS and CS performed for CPD in this large private practice has been developed. It is not accurate at gestational ages less than 37 weeks or greater than 41 weeks.

Acknowledgments

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Discussion

Dr James R. Scott, Salt Lake City, Utah. First, let me congratulate Dr Young for having the intellectual curiosity and motivation to complete this clinical research project. I have always been impressed with busy private physicians who take the time and effort to try to improve our knowledge.

The purpose of this study was to develop a method to predict the probability of CPD and delivery by CS in primiparous women by using 6 demographic characteristics. A reliable way to determine the risk of CS for an individual patient would be very useful to all obstetricians in counseling women, particularly in view of recent discussions on "cesarean on request."

The strengths of this study are the study design, the large number of patients, and the well-defined population. Potential weaknesses include 28 patients with insufficient data, "self-reported" maternal heights, and "self-reported" prepregnancy weights for patients who registered after 20 weeks.

My questions for Dr Young are as follows:

1. The results and conclusions are dependent on the dataset. Exactly who entered the data "under the direct supervision of the nursing supervisor?" Were these attending physicians, nurses, or other staff, and how was the accuracy of the data validated?
2. How were the 6 demographic factors selected? For example, other factors that have been shown to affect cesarean rates are obstetric complications such as preeclampsia, diabetes, use of epidural anesthesia, and induction of labor.
3. I was interested in your definition of CPD and how many physicians were involved in the study. Did every patient have to be in the active phase of labor and receive oxytocin before the diagnosis of CPD was made? Did the management of labor or the rates of the diagnosis of CPD and the cesarean rates vary among the physicians involved? I also wondered why there was no attempt to study or obtain information about the appropriateness of the indication for CS. These seem like important variables that might affect your results.

In closing, the authors are to be congratulated for developing a new system to assess the risk for CS in primigravid women in a specific population. Without discouraging them too much, I should point out that there have been a number of similar demographic studies, scoring systems, and indexes using a variety of techniques with the same overall purpose. However, what initially seemed promising has uniformly been less impressive when used prospectively by other investigators. I encourage the authors to now evaluate their system prospectively. To be convincing and to avoid bias, it would be best to have an independent observer record the demographic data, which is then blinded from the obstetrician managing the patient.

Dr Young (Closing). I want to take this opportunity to thank Dr Scott for his very kind comments and the membership for allowing me to present our work at this meeting. I am very excited about this paper and believe it will be useful. I do not believe this will be the final "formula" for predicting the risk or probability of CS, but believe it is a good start.

Dr Scott's had several questions. His first question concerned the accuracy of the dataset. I did not have the dataset "audited" for accuracy but believe the data are accurate. I do not believe it is perfectly accurate and would concede that some clerical errors would and do occur. However, I believe it is a valid dataset. Mostly the nursing supervisor entered the data, but occasionally clerks did so. The clerical staff did not peruse the charts for data concerning obstetric management or diagnosis but might find the heights and weights in the obstetric record. BMI is calculated automatically in our database.

The second question addressed the factors chosen to use in the calculation formula. Demographic factors that had a know relationship to CPD or CS were chosen. I specifically declined to use factors gathered during labor. The formula has several purposes, but specific evaluation or usage in labor management or obstetric complications was not one of them. I would say the purposes would be the following: For a young women to determine the effect of life style choices such as obesity, weight gain during pregnancy, and age of first pregnancy on her labor performance; to allow