Integrated Approach for Prediction of the Cesarean Section Rate in a Large Private Practice

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Objective: To develop an integrated formula for predicting the probability of Cephalopelvic disproportion/Failure to Progress (CPD) and cesarean section as a function of demographic factors in a middle class private practice. To evaluate risk factors for cesarean section 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 using clinical data from a comprehensive clinical database. We used multi-variate logistic regression analysis to determine the relationship between the probability of cesarean section and cesarean section carried out for CPD and six demographic factors: maternal age, maternal height, initial pregnancy BMI, pregnancy weight gain, gestation age and birth weight. We used three methods to assess the accuracy of the model: Deviance and Pearson Goodness-of-Fit Statistics, Association of Predicted Probabilities and direct comparison of the formula to the actual data. Odds ratios (ORs) with a 95% confidence interval are also calculated for each of these factors.
Results: The overall rate of primiparous cesarean section for the practice is 21.7% with 11.7% carried out for Cephalopelvic disproportion/Failure to Progress (CPD). Formulas were developed for predicting the probability of Cesarean Section and the probability of Cesarean Section due to CPD. Our analysis showed that both the risk of Cesarean Section and the risk of Cesarean Section due to CPD are significantly associated with all the six demographic factors. We also develop an easily usable web-page based calculator to instantly estimate any woman's probability of a Cesarean Section or CPD at the beginning or at the end of her pregnancy.
Conclusion: The risk of Cesarean Section due to CPD is higher for shorter, older, more obese women with large pregnancy weight gains, larger fetal birth weights and longer gestation ages. The total risk of Cesarean Section is higher for shorter, older, more obese women with large pregnancy weight gains, larger fetal birth weights and shorter gestation ages. An accurate formula that predicts the probabilities of Cesarean Section and Cesarean Section done for CPD in this large private practice has been developed.
Key words: Prediction, Integrated formula, Cesarean Section, Cephalopelvic disproportion (CPD), Multi-variate logistic regression.

The Cesarean Section rate in the United States has risen significantly and remains at an elevated level[1]. This is true both in high and low risk populations. The demographics[3,11] of the United States are changing in ways that would predict a continued rise in difficult labors and therefore Cesarean Section[1,2,8,9,11]. Specifically the typical primigravida in the United States is significantly older and heavier with a substantially higher BMI than were comparable women of 30 years ago[2,4,5,12]. Further obesity in the United States is at a much higher level than most, if not all, comparable developed countries[1,12]. In addition current guidelines [4] call for a level of weight gain that exceeds normal pregnancy-related weight gain[5]. Previous studies [1,2,8,10,11] and our own large database demonstrate that the rate of Cesarean Section is related to pregnancy weight gain. Further, Cesarean Section rate for CPD and for other indications is strongly related to birth weight of the fetus as well as the mother's gestational age[2,5]. Since 1993, Gainesville Women's Physicians and subsequently North Florida Women's Physicians has kept a careful and 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 cesarean section. We believe these factors can be evaluated in such a way as to allow reliable statistical prediction of the risk of Cesarean section in a low risk population. This prediction can be made at the beginning of pregnancy on the basis of maternal age, BMI, Height and an estimate of pregnancy weight gain. At the end of pregnancy or at the onset of labor the probability of Cesarean Section can be calculated again with the addition of the gestational age and estimated fetal birth weight while the maternal weight gain is now a known factor. In this study, we will establish the validity of our statistical predictions using all 6 factors (age, height, weight, maternal weight gain, gestational age, and birth weight). We also develop an easily usable web page based calculator[20] to instantly estimate any woman's probability of a Cesarean Section or CPD. We believe this formula offers a method of comparing physician practice patterns and its effect on cesarean section and demonstrates a method of comparing rates of difficult labor and the risk of Cesarean Section in different populations. We believe this is the obligate first step in establishing "appropriateness and comparability" of cesarean section rates.

MATERIALS AND METHODS

Gainesville Women's Physicians and subsequently North Florida Women's Physicians has kept a database of all obstetric patients since 1993. Data entry is carried out under the direct supervision of the nursing supervisor. Data is gleaned from the patient's office chart as well as the Labor and Delivery Record. This data is entered soon after every delivery. There were 7753 deliveries between February 1993 and June 13, 2001. Among these deliveries there were 3383 primiparous deliveries of different gestational ages and including twin gestations with 3355 patients delivering singletons and having sufficient data for analysis with respect to all the six demographic factors. Maternal age was the age in years at the time of 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 prior to 20 weeks. The vast majority of patients presented in the first trimester. If the patient registered after the 20th week a best estimate of pre-pregnancy weight was made based on her self-reported pre-pregnancy 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 cesarean section in primiparas were recorded as Cephalopelvic Disproportion/Failure to Progress (CPD), 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 primipara required little or no progress over a 2-4 hour period with contractions documented to be adequate and cervix dilated to at least 3 or preferably 4 centimeters. Over the period of 8 years the frequency of this diagnosis has been extremely stable over the entire practice.

Regardless of other diagnoses, the diagnosis of Breech virtually guaranteed that there was no attempt at vaginal delivery. Likewise, the diagnosis of Cephalopelvic Disproportion/Failure to Progress (CPD) strongly suggests that a serious attempt at vaginal delivery had occurred. Frequently Cephalopelvic Disproportion/Failure to Progress (CPD) 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. No attempt was made to study or obtain information concerning the intrapartum course of these patients or to validate the appropriateness of the indication for cesarean section. Similarly there was no attempt to assess the prenatal course and any complications or problems that might cause an increase in the risk of cesarean section, and any assessment of cesarean section morbidity was beyond the scope of this study. Specifically this study was primarily about a low risk population.

Because of the large number of data available we modeled all the six factors as continuous independent variables: maternal age in years, maternal height in inches, maternal BMI in Kg/m^2, pregnancy weight gain in pounds, gestation 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 gestation age, pregnancy weight gain with fetal birth weight and fetal birth weight with gestation age. We performed multi-variate logistic regression analysis using the SAS software package.[6] 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. χ^2 tests were used at each step to test the significance of each factor. Deviance and Pearson Goodness-of-Fit Statistics were calculated to access the goodness of fit of the model to the data. The results of the regression were used to build an integrated formula for predicting the probability of Cesarean Section and Cesarean Section due to CPD as a function of the six demographic factors. Association of each factor with cesarean section was expressed as odds ratio (OR) with 95% confidence interval. Direct comparison between the predicted probabilities based on 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 demonstrated in Table 1.The overall rate of primiparous cesarean section for the practice is 21.7% with 11.7% carried out for CPD.

Table 1. Demographic Characteristics (N=3355)

Characteristic	n	%
Maternal age (year), Median=27		
<20	299	8.9%
20-24	865	25.8%
25-29	1231	36.7%
30-34	677	20.2%
>=35	283	8.4%
Maternal height (inch), Median=65		
<62	311	9.3%
62-64	1291	38.5%
65-68	1477	44%
>68	276	8.2%
BMI (Kg/m^2), Median=23.171		
<20.00	546	16.3%
20.00-24.99	1609	48%
25.00-29.99	703	21%

30.00-39.99	431	12.8%
>=40.00	66	2%
Gestation age (week), Median=39		
<37	233	6.9%
37	200	6.0%
38	458	13.7%
39	863	25.7%
40	1040	31%
41	495	14.8%
42	66	2%
Weight gain during pregnancy (pound), Median=31		
<25	852	25.4%
25-35	1383	41.2%
>35	1120	33.4%
Fetal birth weight, Median=3430		
<2500	138	4.1%
2500-2999	453	13.5%
3000-3449	1336	39.8%
3500-3999	1074	32%
4000-4499	296	8.8%
>=4500	58	1.7%

The notations used in the integrated formulas are as follows:

Prob(CPD): Probability of Cephalopelvic disproportion/Failure to Progress (CPD)
Prob(C/S): Probability of Cesarean Section
MA: Maternal age (year)
MH: Maternal height (inches)
BMI: Pregnancy BMI
WG: Weight gain during pregnancy (pounds)
GA: Gestation age (weeks)
BW: Fetal birth weight (gram)

Formula (1) and (2) predict the probability of CPD and overall Cesarean Section as a function of the six demographic factors.

(1) $$\text{Prob(CPD)} = \frac{\text{Odds(CPD)}}{1+\text{Odds(CPD)}},$$

where $$\text{Odds(CPD)} = e^{16.6242-0.3808\times GA+0.0692\times MA-0.2063\times MH+0.0109\times WG-0.00545\times BW+0.0931\times BMI+0.000174\times BW\times GA}$$

(2) $$\text{Prob(C/S)} = \frac{\text{Odds(C/S)}}{1+\text{Odds(C/S)}},$$

where $$\text{Odds(C/S)} = e^{26.3663-0.7095\times GA+0.0811\times MA-0.1374\times MH+0.0815\times WG-0.00719\times BW+0.0830\times BMI-0.0000178\times BW\times WG+0.000213\times BW\times GA}$$

We used three different methods to assess the accuracy of these formulas. First, the Deviance and Pearson types of Goodness-of- Fit tests were performed, both of which resulted in a large P-value (larger than 0.10), 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 concordance (78.3% and 69.9% respectively) and low percentages of discordant (21.3% and

29.6% respectively), which further verified that the model is a good fit. Moreover, we compare the predicted rates of CPD and Cesarean directly with the actual rates of CPD and Cesarean Section by constructing Figure 1 and Figure 2. These two 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 of size 100. The predicted and actual total number of CS and CPD of each group are calculated and plotted on the graphs. From these graphs we observe that the predicted curves track the actual curves reasonably well.

Figure 1.Comparison of rates of predicted and actual CPD

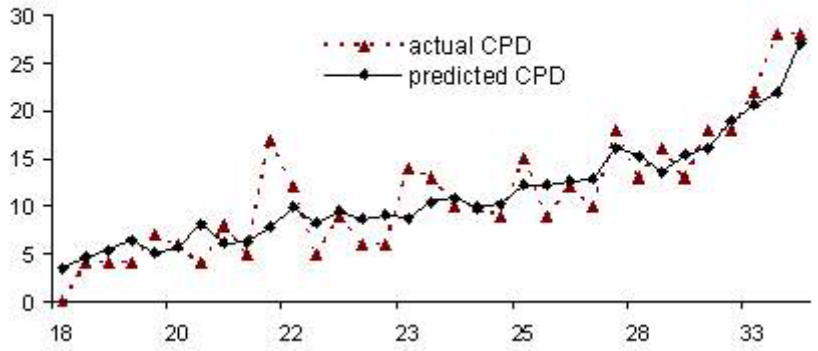
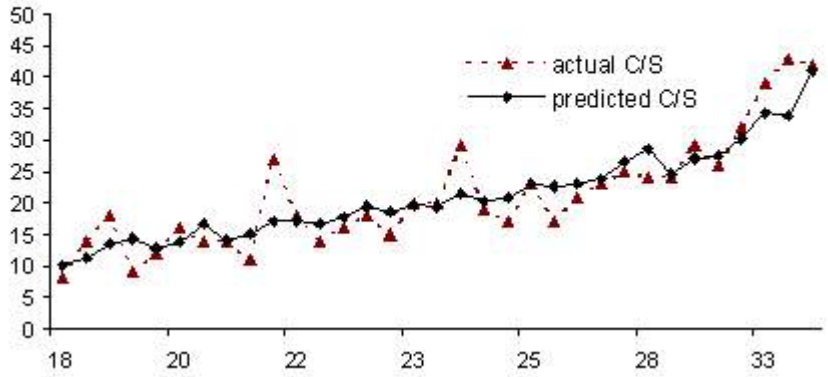


Figure 2. Comparison of rates of predicted and actual C/S



Using Formula (1) and Formula (2), we can easily estimate the risk of CPD and Cesarean section. For example, CPD rate and overall Cesarean Section rate of a 29-year old primigravida who is 63-inch tall with a weight of 132 pounds, a pregnancy weight gain of 42 pounds, an estimated fetal birth weight of 3700 grams and a gestation age of 41 weeks are 23.8% and 32.7% respectively. Figure 3 through 8 depict the association of the probability of CPD and overall Cesarean Section with each one of the six variables with the other five controlled at the median.

Figure 3. Effect of Age with other factors controlled

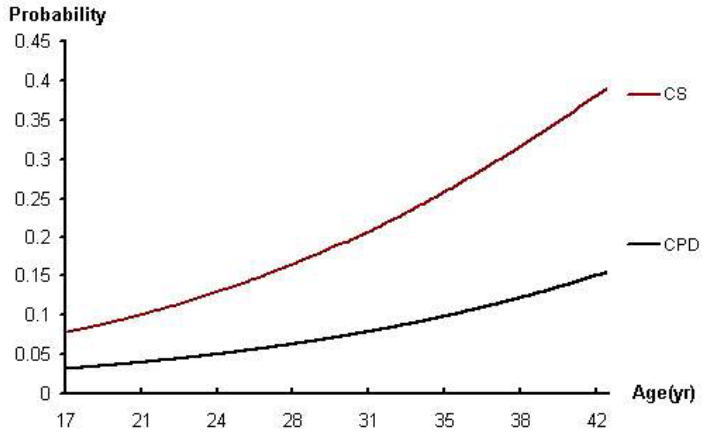


Figure 4. Effect of BMI with other factors controlled

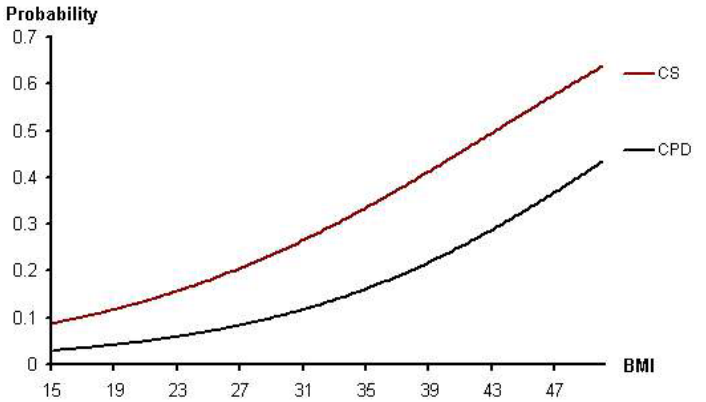


Figure 5. Effect of Height with other factors controlled

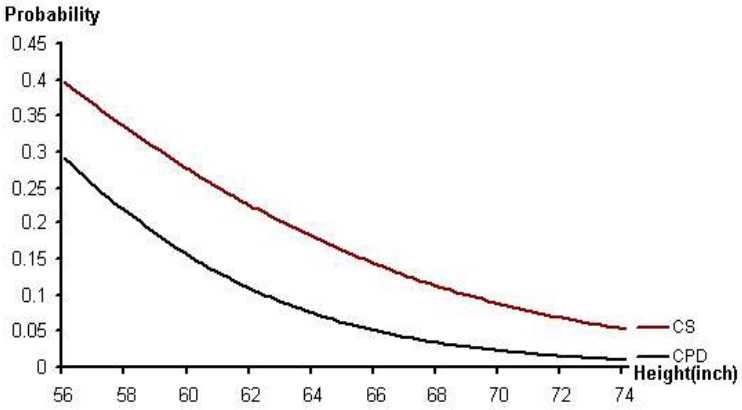


Figure 6. Effect of Weight-Gain with other factors controlled

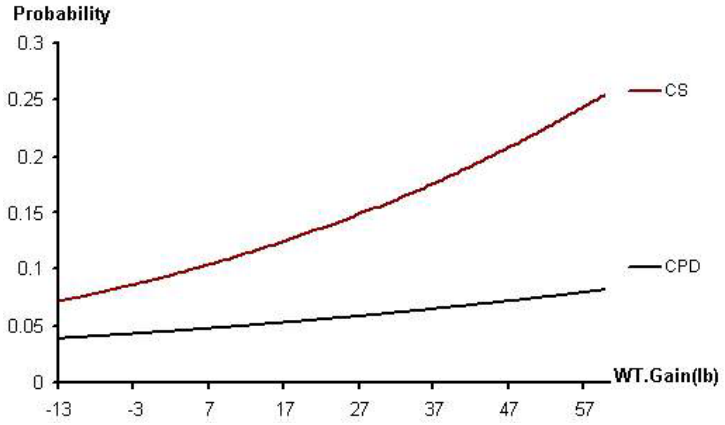


Figure 7. Effect of Fetal Weight with other factor controlled

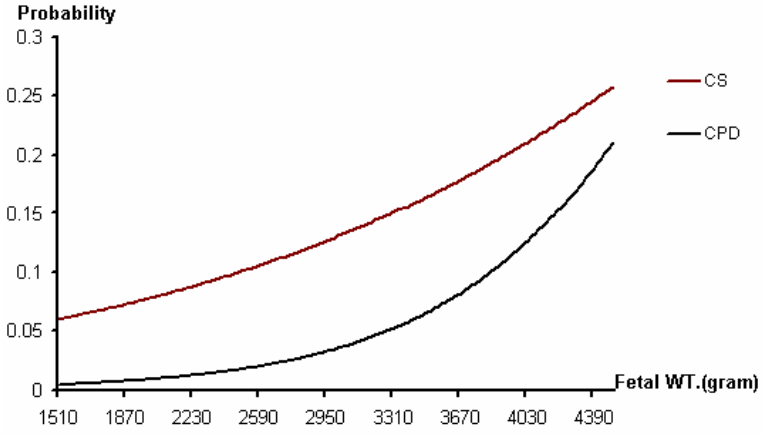


Figure 8. Effect of Gest. Age with other factors controlled

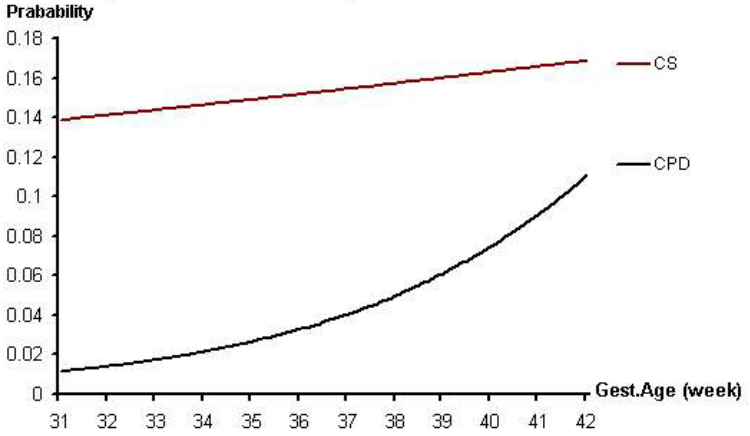


Table 2 and Table 3 demonstrate the progression of ORs of CPD and overall Cesarean Section as the six factors increase or decrease.

Table 2. Progression of adjusted Odds Ratio of CPD.

Factor	Step size	Progression in OR(CPD)	95% CI

Maternal age	Every 3 years older	1.228	(1.154, 1.309)
Maternal height	Every 2 inches shorter	1.506	(1.374, 1.648)
BMI	Every 3 (Kg/m^2) of increase	1.320	(1.246, 1.401)
Gestation age	Every 1 week longer	1.232	(1.113, 1.363)
Weight gain during pregnancy	Every 5 pounds more	1.057	(1.005, 1.110)
Fetal birth weight	Every 250 grams more	1.423	(1.389, 1.494)

Table 3. Progression of adjusted Odds Ratio of C-Section.

Factor	Step Size	Progression in OR(C/S)	95% CI
Maternal age	Every 3 years older	1.268	(1.237, 1.300)
Maternal height	Every 2 inches shorter	1.304	(1.260, 1.350)
BMI	Every 3 (Kg/m^2) of increase	1.290	(1.259, 1.321)
Gestation age	Every 1 week shorter	1.073	(1.039, 1.109)
Weight gain during pregnancy	Every 5 pounds more	1.094	(1.074, 1.115)
Fetal birth weight	Every 250 grams more	1.133	(1.103, 1.164)

We noticed that increase in OR of CPD is associated with decrease in maternal height an increase in maternal age, pregnancy BMI, pregnancy weight gain, gestation age and birth weight. For instance, there is a 5-fold 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 pounds to 65 pounds doubles the OR of CPD. The association of the probability of cesarean section and the association of the probability of CPD are similar in all factors except one: gestation age, which has a negative effect on the probability of cesarean section but a positive effect on CPD.

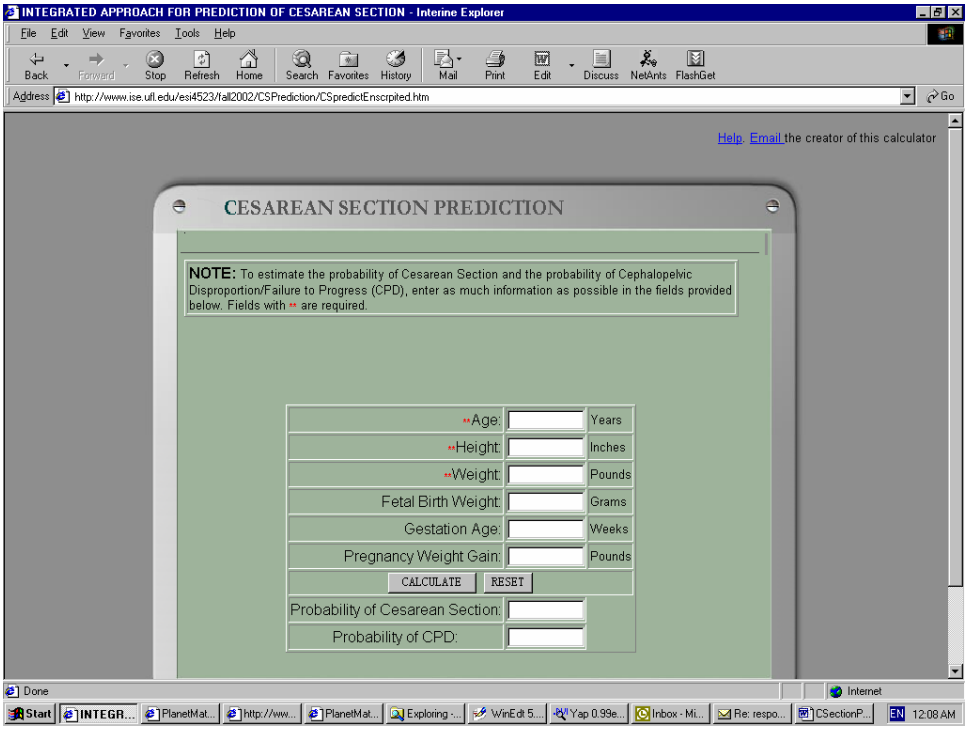
Finally, we developed an easily usable web page based calculator[14] to instantly estimate any woman's probability of a Cesarean Section or CPD. See Figure 9. This calculator can be used to predict the risk of CPD and overall Cesarean Section at the beginning of pregnancy on the basis of maternal age, BMI, Height and an estimate of pregnancy weight gain. 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 while the maternal weight gain is now a known factor.

DISCUSSION

This is a sophisticated statistical evaluation of one private practice that has a large and consistent obstetric database. The substantial relationship between maternal demographics and cesarean section have been observed by others[1,2,5,7,8,9,10,11,13]. However, these relationships have been described individually and never in an integrated mathematical fashion. The results of this study indicates that a global formula for predicting the "probability" of cesarean Section and the risk of difficult labor (CPD/Failure to Progress) in any primipara both at the beginning of her pregnancy and prior to labor is possible. An easily usable web-based calculator was developed to allow an almost instant prediction of the probability of Cesarean Section 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 cesarean section 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 this same token this formula offers a method of comparing physician practice patterns and its effect on cesarean section and moreover, it demonstrates a method of comparing rates of difficult labor and the risk of Cesarean Section in

different populations. Our efforts to determine an appropriate frequency of labor intervention and Cesarean Section have foundered on the difficulty in comparing different obstetric populations. In the past we have simply assumed 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.

Figure 9. Web-based calculator for predicting CPD and C/S



In the United States, Cesarean Section 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 cesarean section. Finally, The United States suffers from a difficult tort system making the cost of a bad outcome both devastatingly high and capricious. We believe that an accurate mathematical description of the demographic risk of Cesarean Section will allow an assessment of the real risk of difficult labor as opposed to the perceptions and possible misperceptions of our present medico-legal 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 which may be at higher risk of difficult labor. We hope to identify certain situations where the probability of a successful vaginal delivery is too low to justify a trial of labor. Further there is 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 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 Cesarean Section due to CPD is higher for shorter, older, more obese women with large pregnancy weight gains, larger fetal birth weights and longer gestation ages. The total risk of Cesarean Section is higher for shorter, older, more obese women with large pregnancy weight gains, larger fetal birth weights and shorter gestation ages. An accurate

formula that predicts the probabilities of Cesarean Section and Cesarean Section done for CPD in this large private practice has been developed.

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