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ORIGINAL PAPER

Meteorological factors and timing of the initiating event of human parturition

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Abstract The aim of this study was to determine whether meteorological factors are associated with the timing of either onset of labor with intact membranes or rupture of membranes prior to labor—together referred to as 'the initiating event' of parturition. All patients delivering at Evanston Hospital after spontaneous labor or rupture of membranes at ≥20 weeks of gestation over a 6-month period were studied. Logistic regression models of the initiating event of parturition using clinical variables (maternal age, gestational age, parity, multiple gestation and intrauterine infection) with and without the addition of meteorological variables (barometric pressure, temperature and humidity) were compared. A total of 1,088 patients met the inclusion criteria. Gestational age, multiple gestation and chorioamnionitis were associated with timing of initiation of parturition ($P<0.01$). The addition of meteorological to clinical variables generated a statistically significant improvement in prediction of the initiating event; however, the magnitude of this improvement was small (less than 2% difference in receiver-operating characteristic score). These observations held regardless of parity, fetal number and gestational age. Meteorological factors are associated with the timing of parturition, but the magnitude of this association is small.

Keywords Parturition · Weather · Statistical model · Labor

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Introduction

Despite the advances of modern science, the mechanisms governing the timing of spontaneous labor in women remain a mystery. This statement applies equally well to physiologic and pathologic labor conditions such as preterm labor, preterm premature rupture of the membranes and prolonged gestation. There is a persistent perception that the onset of labor is influenced by environmental factors such as oncoming storms or phases of the moon. Yet the relatively scant medical literature on the topic has yielded mixed judgments on that perception, with only approximately half of published studies demonstrating statistically significant associations between environmental factors, in particular falling barometric pressure, and the onset of labor (Steinman and Kleiner 1978; Driscoll 1995; King et al. 1997; Noller et al. 1996; Trap et al. 1989; Stern et al. 1988; Polansky et al. 1985; Marks et al. 1983).

In the present study, we use a novel and robust statistical approach to mine clinical and meteorological data for a relationship between atmospheric conditions and labor at a single hospital in Evanston, Illinois, north of Chicago. The period under study, the summer, fall and early winter of 2001, included a record-setting 2-month rainy period (mid-July to mid-September), in which there were eight major storms, of which two were '100-year event' rainfalls (Changnon and Westcott 2002). This period was chosen specifically because it would tend to accentuate any potential impact of weather patterns on the initiating event of parturition.

Materials and methods

Clinical data

This study was approved by the Institutional Review Board of NorthShore University HealthSystem. Medical records were reviewed for all patients delivering between 1 July and 31 December 2001 at Evanston Hospital [situated 0.5 miles (~0.8 km) west of the Lake Michigan shoreline and 3.5 miles (~5.6 km) north of Chicago's northern border]. Patients with spontaneous onset of labor with intact fetal membranes leading to delivery (defined as the presence of regular uterine contractions plus either documented cervical change or cervical effacement of 80% or more) or spontaneous rupture of membranes prior to labor (referred to in clinical terms as premature rupture of membranes or PROM) were included in the study. Either one of these events (onset of labor or PROM) was considered an 'initiating event of parturition'. Patients were considered to be at term at ≥37 completed weeks and preterm at <37 weeks of gestation. Patients were excluded if they had scheduled deliveries (cesarean section or induction of labor), were of gestational age less than 20 weeks, had an intrauterine fetal demise or a major fetal anomaly, or resided in a zip code outside of a 45-km radius of O'Hare International Airport (the measuring site for meteorological variables). Multiple gestation and preterm labor were not causes for exclusion.

The time of spontaneous onset of labor with intact membranes or rupture of membranes prior to labor reported by the patient to the admitting nurse in the Labor and Delivery unit was used, unless spontaneous labor or rupture of membranes was observed directly in patients already hospitalized for another reason. Clinical variables extracted from review of the electronic medical record included maternal age, zip code of residence, gestational age (based on either last menstrual period confirmed by ultrasound or ultrasound only when discrepancies between these two methods exceeded accepted standard thresholds), parity (i.e. whether or not the patient had a prior delivery after 20 weeks), plurality (singleton or multiple gestation), date and time of onset of uterine contractions, date and time of rupture of membranes, chorioamnionitis (temperature >38°F, uterine tenderness and/or foul-smelling amniotic fluid), and date and time of delivery.

Meteorological variables

Hourly barometric pressure, air temperature and humidity measurements obtained at O'Hare International Airport for the period from 9 June to 31 December 2001 were downloaded from the National Climatic Data Center (NCDC) website (http://www.ncdc.noaa.gov/oa/ncdc.html). This time span allowed collection of meteorological variables beginning 3 weeks prior to delivery through the initiating event of parturition for all participating women.

Construction of predictive models

Analytical methods were designed to test the hypothesis that the inclusion of meteorological variables improves upon the power of clinical variables alone for prediction of either of the 'initiating events' (i.e., labor with intact membranes or rupture of membranes prior to labor). Random effects logistic regression was conducted first to estimate the independent effect of each of the clinical and meteorological variables on the initiating event. Receiver-operating characteristic (ROC) analysis was then conducted, drawing on estimates from the regression models to measure the predictive value of individual models.

To construct the predictive models, each initiating event of parturition was compared to two randomly selected 'non-initiation' events (i.e., points in time during which the patient had neither labor onset nor pre-labor rupture of membranes) from the 3 weeks preceding delivery in the same patient. This method was chosen to account for the hypothetical effect of biochemical and anatomical changes in the weeks leading up to delivery that may sensitize the gestation to environmental or other factors (thus lowering the threshold for labor). Preliminary analyses had demonstrated that the predictive ability of the models was not improved by including more than two 'non-initiation' events per patient (data not shown).

After sequestering 200 patients for validation studies, logistic regression analyses were conducted in the remaining 888 patients to estimate the independent effect of each of the independent variables (clinical and meteorological) on the dependent variables (i.e., the presence or absence of each of the following three conditions: no initiating event, labor with intact membranes, or rupture of membranes prior to labor). Variable coefficients were unconstrained so that each variable could contribute independently to prediction of the outcome. It was possible therefore for only some of the weather variables to be statistically significant predictors.

To account for a wide range of possible relationships between weather and labor, and based upon findings reported in the preexisting literature on the topic, 12 different random effects logistic regression models incorporating both meteorological and clinical variables were compared with a 13th model that used clinical variables alone (see Table 1). The 12 regression models that incorporated meteorological variables differed from each other by taking into account three different types of potential effects of weather:

(1) The existence of a time lag between weather conditions at a given point in time and their influence on the subsequent initiating event of parturition.

    To account for such effects, models were constructed that included lags of 0, 3, 6, 12 or 24 h. Three-hour intervals were chosen for the initial lag times because of prior studies that found significant associations between barometric pressure changes and labor onset (Noller et al. 1996) or rupture of membranes (Polansky et al. 1985) within this time frame.

(2) Potential interaction between pressure, temperature and humidity.

    To account for the possibility that the effect of one weather variable may depend on a different weather variable, interaction terms between each of the three weather variables (i.e., pressure and temperature, pressure and humidity, and temperature and humidity) were included.

(3) The potential effect of a sustained directional change in weather patterns (i.e., a sustained increase or decrease in weather variables of 6 or 12 h duration).

In order to account for the possibility that gestational age has a non-linear effect on the outcome (for example that each additional day has a greater impact late in pregnancy than early in pregnancy), gestational age was included in the model both on its own and as a squared term.

Secondary analyses were then conducted to examine the effect of weather variables on the initiating event of parturition in clinically defined subgroups of patients. The logistic regression analyses were repeated for each of the three types of occurrences (no event, spontaneous labor with intact membranes or rupture of membranes prior to labor) according to the following four types of clinically relevant variables:

(1) Gestational age: 72 patients delivering prematurely (prior to 37 completed weeks) and 816 patients delivering at term (≥37 weeks)
(2) Parity: 531 parous patients and 357 non-parous patients
(3) Multiple gestation: 851 singleton gestations and 37 multiple gestations
(4) Infection: 75 patients with clinical chorioamnionitis and 813 patients without chorioamnionitis. This variable was included as a potential marker for antenatal infection, which might in turn lead to labor

Model validation

Each model was evaluated with respect to its ability to predict whether any given patient will experience an initiating event at a particular time. Predictive power was quantified by ROC curves (Hanley and McNeil 1982). ROC curves plot the sensitivity of a classifier as a function of 1−specificity (or, equivalently, true positive rate as a function of false positive rate). The ROC score is the area under this curve. An algorithm that correctly categorizes all events would receive an ROC score of 1, whereas a random ranking would receive a score of approximately 0.5. The closer the ROC score is to 1, the better the predictive performance of the model. By comparing the ROC score of two models, we test the hypothesis that one model is a better predictor of initiation of labor than the other.

We used an approach known as three-fold cross-validation to compare the performance of the various models. The data set consisted of 1,088 patients, 200 of whom were sequestered for validation studies. Three-fold cross-validation divides the remaining population of 888 patients randomly into thirds. Two-thirds of the patients are used to train a computational classifier, and the final one-third is used to test the error rate of the classifier. This is done three times, with each third serving twice as part of the training set and once as the testing set. To improve our statistical power, the random three-way split and cross-validation of the 888 patients was performed five times. This procedure results in 15 ROC scores for each predictive model. To compare two models, we use a Wilcoxon signed-rank test to ask whether the median ROC score from one model is different from the median ROC score from an alternative model.

One of the advantages of the cross-validation method and the use of a sequestered test set is that these approaches prevent the possibility of ‘over-fitting’ the data (i.e., artifactually improving the regression model by adding variables). Over-fitting is avoided in this case because we only report results with respect to data that was not used to train the model.

Two final models (the model using clinical data only and the best-performing weather-inclusive model) were used for confirmatory analysis in the 200 sequestered patients.

Table 1 Description of the 12 weather-inclusive models (Models 1.1–1.12) and tests of statistical significance (Wilcoxon signed rank test) of the improvement in mean receiver-operating characteristic (ROC) scores for each compared to the weather-exclusive model (Model 2). Each of the 12 weather-inclusive models improves to a minimal degree on the predictive ability of the no-weather model. Each model includes the following clinical variables: estimated gestational age, gestational age squared, maternal age, and variables indicating multiple gestations (versus singletons), parity (versus nulliparity), and the presence or absence of infection. Additional weather variables are described below according to their inclusion in each of the 12 weather models

	Barometric pressure					Temperature					Humidity					Interactions[b]	Extended change over 6h[c]	Extended change over 12h	ROC score	*P* value (compared to Model 2)
Lag[a]	0	3	6	12	24	0	3	6	12	24	0	3	6	12	24					
Model 1.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				0.76773	0.00021
Model 1.2	X	X	X			X	X	X			X	X	X						0.76861	0.00029
Model 1.3	X			X	X	X			X	X	X			X	X				0.76962	0.00010
Model 1.4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			0.76651	0.00038
Model 1.5	X	X	X			X	X	X			X	X	X			X			0.76736	0.00029
Model 1.6	X			X	X	X			X	X	X			X	X	X			0.76846	0.00011
Model 1.7	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		0.76663	0.00168
Model 1.8	X	X	X			X	X	X			X	X	X				X		0.76757	0.00038
Model 1.9	X			X	X	X			X	X	X			X	X		X		0.76762	0.00066
Model 1.10	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	0.76773	0.00021
Model 1.11	X	X	X			X	X	X			X	X	X					X	0.76745	0.00107
Model 1.12	X			X	X	X			X	X	X			X	X			X	0.76802	0.00050
Model 2 (weather-exclusive)																			0.76075	–

[a] Lag describes the length of time prior to the onset of labor from which the weather variable was measured

[b] Interactions measured as the product of pressure and temperature, pressure and humidity, and temperature and humidity

[c] Extended change measured as consistent increases or decreases in each weather variable over the specified number of hours (e.g., extended change of temperature at 6 h means that temperature was higher 6 h prior to the event than 3 h prior to the event, and higher at 3 h than at 0 h prior to the event).

Results

Among 1,867 women delivering between 1 July and 31 December 2001, 751 were ineligible, and 28 charts had missing data. Thus, 1,088 women were included in the study. Of these 1,088 women, 723 (66.5%) experienced onset of labor with intact membranes as the initiating event of parturition, while 365 (33.5%) had premature rupture of membranes as the initiating event. The maternal age (mean ±standard deviation) in the study population was 32.0±5.4, and the gestational age was 39.1±2.0 weeks; 4% of gestations were multiple (twins or higher order) and 37% of patients were nulliparous. Preterm birth (prior to 37 completed weeks) occurred in 8.0% of deliveries.

There was a diurnal variation in the initiating event of parturition, with the most common time for the initiating event being between 3:00 and 6:00 a.m. (Fig. 1a; $P<0.01$, Kolmogorov-Smirnov test for uniformity). Not surprisingly, there was a corresponding inverse association with ambient temperature (Fig. 1b). During the period under study, there were two separate severe “100-year event” storms. No consistent pattern of labor onset or membrane rupture was observed in association with these two storms.

Table 1 shows the results of an analysis of cross-validated ROC scores, in which the performance of the 12 predictive models that make use of both clinical and meteorological variables is compared with the model based upon clinical variables alone. Each of the 12 weather-inclusive models (Models 1.1–1.12) performs better as a predictor of an initiating event of labor than the non-weather model (Model 2), with significant differences in ROC scores ($P<0.002$) in each case. To avoid multiple testing issues, we did not perform comparisons among the 12 weather-enhanced models; however, a Bonferroni adjustment to the traditional P value threshold for significance of 0.05 would yield a new threshold of 0.05/12=0.0042—still significant for each of the weather-inclusive models. Also, because we did not compare the 12 weather-inclusive models to each other, we cannot say whether any of the differences among these 12 models is significant. Among these 12 models, model 1.3 (which includes variables representing current pressure, temperature, and humidity and lags of 12 and 24 h) yields the lowest P value and therefore was used in subsequent comparisons as the ‘best-performing’ of the weather-inclusive models.

The magnitude of the improvement in predictive ability afforded by inclusion of meteorological variables is small. Figure 2a compares the performance of Model 1.3 and the weather-exclusive model (Model 2) for one representative test set selected randomly from the cross-validation experiments. The weather-inclusive model has an ROC score of 0.757, whereas the no-weather model has an ROC score of 0.744. Thus, the weather-inclusive model outperforms the no-weather model, but only slightly. Figure 2b plots the ROC scores of these two models (Models 1.3 and 2) for all 15 test sets. In the figure, all but one of the 15 points lies above the line $y=x$, indicating that the weather-inclusive model almost always performs better. However, the magnitude of the difference in ROC score is consistently quite small: the ROC score of the weather-inclusive model never exceeds the score of the no-weather model by more than 2% (maximum 1.98%).

To test whether the predictive performance of meteorological factors is an artifact of the diurnal variation in the initiating event of labor (i.e., that labor is more common at night, when temperatures are lower), we performed a second round of cross-validation experiments, in which each randomly selected ‘non-initiating’ event was from the same time of day as the corresponding initiating event. Despite controlling for time of day, the weather-enhanced model (Model 1.3) consistently outperformed the no-weather model. The P value from the corresponding Wilcoxon signed rank test was 0.00209.

We next tested whether incorporating weather variables improves predictive ability for initiation of parturition in various subsets of patients, defined by four binary variables that might have independent effects on the timing of delivery: term or pre-term initiation of labor, parity or non-parity, singleton or multiple gestation and the presence or absence of chorioamnionitis during labor (a potential indicator of preexisting infection). For this analysis, we used non-initiating events with matched time of day relative to the corresponding initiating event. Inclusion of meteorological variables improves the predictive ability of the clinical variables for all of the patient subgroups ($P<0.02$ for all) with the exception of those with chorioamnionitis ($P=0.75$).

We examined the impact of the individual components of the weather-inclusive and weather-exclusive models (1.3 and 2, respectively); the results are described in Table 2. Statistically significant clinical predictors of initiation of parturition in both the weather inclusive and weather-exclusive models included increasing gestational age, multiple gestation and chorioamnionitis during labor ($P<0.01$). None of the individual weather variables are statistically significant predictors of initiation of parturition.

Finally, after training our two models on the set of 888 patients, we applied the trained models to the 200 patients that were sequestered at the beginning of the study. For this analysis, we used two time-of-day matched controls for each initiating event. The weather-exclusive model achieved an ROC score of 0.729, whereas the weather-enhanced model achieved an ROC score of 0.733, confirming the small increase in predictive value afforded by inclusion of meteorological variables.

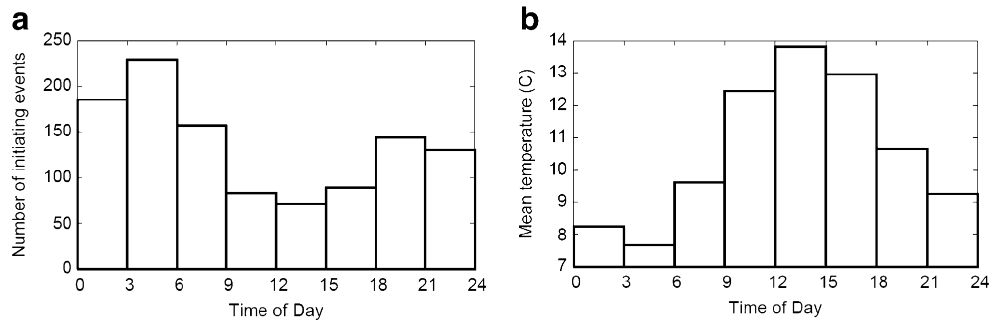

Fig. 1 Diurnal variation in **a** the timing of the initiating event of parturition, and **b** mean temperature

Discussion

This study demonstrates that inclusion of weather variables improves the ability of a model based on clinical factors alone to predict the initiating event of labor, regardless of gestational age, parity and multiple gestation. However, the magnitude of the effect was quite small (less than 2% improvement in ROC score) and was not accountable by any individual weather variable. This small effect is likely to be dwarfed at almost any given moment by other factors and thus is not likely to be very useful in clinical practice.

Previous studies addressing the same or similar questions have yielded mixed results. Among reports demonstrating an association between meteorological factors and parturition were some showing a positive effect of falling barometric pressure (King et al. 1997; Polansky et al. 1985) and at least one showing an effect in the opposite direction (Noller et al. 1996). Other studies identified no independent relationship between spontaneous labor or pre-labor rupture of membranes and either barometric pressure or phases of the moon (Trap et al. 1989; Stern et al. 1988; Marks et al. 1983; Morton-Pradhan et al. 2005).

Limitations of previously published reports in humans include small numbers of patients (Steinman and Kleiner 1978; Polansky et al. 1985; Marks et al. 1983), non-exclusion of induced labor (Driscoll and Merker 1984), the use of time of birth rather than labor onset or membrane rupture as the independent variable (Driscoll 1995; Trap et al. 1989; Morton-Pradhan et al. 2005), and using calendar date (an imprecise measure) as opposed to date-and-time (Morton-Pradhan et al. 2005). Conflicting results include findings from a single author, who in one study found a strong association between birth frequency and cold fronts (Driscoll and Merker 1984), and in a subsequent study reported the opposite (Driscoll 1995). The present study overcomes many of the above deficiencies. We did not exclude premature deliveries, unlike most of the prior studies, because the physiology of preterm labor may differ from that of term labor and might have been more susceptible to atmospheric influences. We also did not exclude co-existing conditions such as vaginal bleeding or polyhydramnios (except in cases where such conditions resulted in induction of labor or scheduled cesarean section) because we made no assumptions

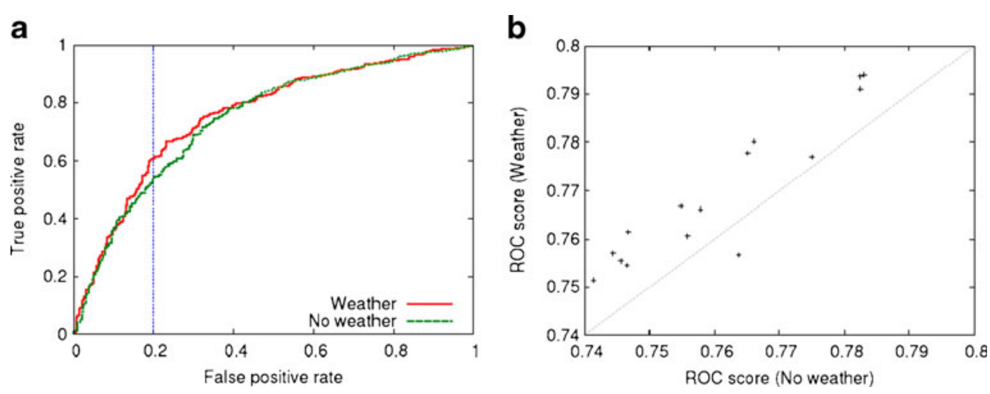

Fig. 2 Receiver-operating characteristic (ROC) analysis comparing weather-inclusive and weather-exclusive prediction of the initiating event of parturition. **a** ROC curve for the weather-exclusive model (Model 2) and one of the weather-enhanced models (Model 1.3), computed with respect to a test set selected at random from the cross-validation experiment. The test set contains 296 initiating events (one-third of 888 patients) and 592 non-initiating events, and each model predicts for each of these 888 events the probability of it being an initiating event of labor. **b** Scatter plot of ROC scores for the weather-enhanced model (*y*-axis) as a function of the no-weather model (*x*-axis) for all 15 test sets, demonstrating consistently improved performance by inclusion of the meteorological variables

Table 2 Regression results for Model 1.3 (clinical plus meteorological variables) and Model 2 (clinical variables alone): prediction of initiating event of parturition

Variable	Model 1.3		Model 2	
	Odds ratio	z-statistic	Odds ratio	z-statistic
Estimated gestational age	0.01**	−11.42	0.01**	−11.59
Estimated gestational age squared [a]	1.1**	12.62	1.1**	12.79
Maternal age	1.0	−0.78	1.0	−0.84
Multiple gestation	5.0**	6.48	5.3**	6.75
Parity	1.0	−0.14	1.0	0.08
Chorioamnionitis	0.6**	−2.77	0.6**	−2.76
Barometric pressure	0.7	−0.65		
Barometric pressure (12-h lag)	0.9	−0.19		
Barometric pressure (24-h lag)	0.9	−0.28		
Temperature	1.0	0.50		
Temperature (12-h lag)	1.0	−1.04		
Temperature (24-h lag)	1.0	−0.96		
Humidity	1.0	−0.05		
Humidity (12-h lag)	1.0	0.28		
Humidity (24-h lag)	1.0	−0.36		

*$P<0.05$, ** $P<0.01$

[a] Joint test of gestational age and gestation age squared, $P<0.001$

regarding the influence of weather on timing of parturition in those cases.

The present study was carefully designed to include rupture of membranes prior to labor and labor with intact membranes both separately and together as alternative types of initiating events of parturition. The period under study included a record-setting 2-month rainy period in which there were eight major storms, of which two were '100-year event' rainfalls (Changnon and Westcott 2002). This period was chosen specifically because it would tend to accentuate any potential impact of weather patterns on labor onset. Further, in order to account for the possibility that meteorological variables initiate labor in a delayed fashion, the analysis was conducted with lags extending backward in time up to 24 h prior to the initiating event. We focused on the 3 weeks immediately prior to delivery to address the possibility of a gestational-age dependent 'priming effect' that increases susceptibility to environmental influences as labor approaches.

We also confirmed a previously noted diurnal pattern of labor onset and its corresponding inverse association with ambient temperature (i.e., that more initiation events occurred at night, when temperatures are cooler than in the daytime). The identification of this inverse correlation with temperature can be viewed as a positive control, as it demonstrates that our methods are sensitive enough to identify a known effect of small magnitude. We further showed that the added predictive value of meteorological factors is not an artifact of this diurnal pattern.

Our results demonstrate that, as expected, the clinical variables of advancing gestational age, multiple gestation and the presence of infection are significantly associated with the timing of the initiating event. However, these factors do not constitute useful predictors in their own right (ROC score only approximately 0.77). We made no attempt to develop a comprehensive model of the onset of parturition based upon clinical or other factors. The potential relationship between the day-to-day timing of labor onset or rupture of the fetal membranes and variables such as race, obstetrical history, socioeconomic factors and the like (which have been associated with preterm birth) was not addressed in our study and have not been determined. Also, our results may not be generalizable to different climates, geographic regions, patient populations and other particulars.

Why is it important to characterize the relationship between weather and labor? A potentially useful impact on the staffing of labor rooms has been cited (Noller et al. 1996; Morton-Pradhan et al. 2005); however, even the largest effects demonstrated in the literature are too small to inform staffing decisions. More importantly, perhaps, this avenue of research has the potential to answer remaining questions regarding the physiology of parturition in both normal and pathological circumstances, areas that remain poorly understood despite decades of research. It appears that such answers are not 'blowing in the wind'.

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References

Changnon SA, Westcott NE (2002) A record number of heavy rainstorms in Chicago in 2001. Trans Ill State Acad Sci 95:73–85

Driscoll DM (1995) Weather and childbirth: a further search for relationships. Int J Biometeorol 38:152–155

Driscoll DM, Merker DG (1984) A search for associations between weather and the onset of human parturition. Int J Biometeorol 28:211–224

Hanley JA, McNeil BJ (1982) The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology 143:29–36

King EA, Fleschler RG, Cohen SM (1997) Association between significant decrease in barometric pressure and onset of labor. J Nurse Midwifery 42:32–34

Marks J, Church CK, Benrubi G (1983) Effects of barometric pressure and lunar phases on premature rupture of the membranes. J Reprod Med 28:485–488

Morton-Pradhan S, Bay RC, Coonrod DV (2005) Birth rate and its correlation with the lunar cycle and specific atmospheric conditions. Am J Obstet Gynecol 192:1970–1973

Noller KL, Resseguie LJ, Voss V (1996) The effect of changes in atmospheric pressure on the occurrence of the spontaneous onset of labor in term pregnancies. Am J Obstet Gynecol 174:1192–1197, discussion 1197–1199

Polansky GH, Varner MW, O'Gorman T (1985) Premature rupture of the membranes and barometric pressure changes. J Reprod Med 30:189–191

Steinman G, Kleiner GJ (1978) Spontaneous premature rupture of membranes. Correlation with ambient atmospheric pressure. N Y State J Med 78:900–901

Stern EW, Glazer GL, Sanduleak N (1988) Influence of the full and new moon on onset of labor and spontaneous rupture of membranes. J Nurse Midwifery 33:57–61

Trap R, Helm P, Lidegaard O, Helm E (1989) Premature rupture of the fetal membranes, the phases of the moon and barometer readings. Gynecol Obstet Investig 28:14–18