OBSTETRICS

Time from neuraxial anesthesia placement to delivery is inversely proportional to umbilical arterial cord pH at scheduled cesarean delivery

Rebecca R. Rimsza, MD; William M. Perez, MD; Shilpa Babbar, MD, MS; Megan O'Brien, DO; Laura K. Vricella, MD

BACKGROUND: Neuraxial block-related hypotension and maternal obesity contribute to uterine hypoperfusion and decreased umbilical arterial pH at cesarean delivery. Between the time of anesthesia placement and delivery, the fetus may be exposed to a hypoperfused uterine environment without surgeon awareness of fetal compromise.

OBJECTIVE: We sought to evaluate neonatal umbilical arterial pH according to predelivery time intervals at scheduled term cesarean.

STUDY DESIGN: We performed a retrospective cohort study of cesarean deliveries between September 2014 and February 2017. Singleton gestations undergoing scheduled cesarean delivery under spinal anesthesia between 37 and 41 weeks with a reassuring preoperative nonstress test were included. Time intervals between operative room entry, spinal anesthesia placement, skin incision, uterine incision, and delivery were calculated. The primary outcome was umbilical arterial pH. Demographic data, maternal blood pressures, predelivery time intervals, and delivery outcomes were analyzed according to umbilical arterial pH intervals of <7.0, 7.01—7.10, 7.11—7.20, 7.21—7.30, and >7.30. Umbilical cord gas analytes and neonatal outcomes were analyzed by spinal to delivery time. Stepwise linear regression was performed to identify predictors of decreasing umbilical arterial pH. Receiver-operator characteristic curves were calculated for spinal to delivery time and umbilical arterial pH <7.0 and 7.1.

RESULTS: Among 527 included participants, median umbilical arterial pH was 7.27 [interquartile range, 7.23—7.29] and body mass index was 35 kg/m^2 [interquartile range, 30—41]. Both maternal body mass index and hypotensive episodes increased with decreasing umbilical arterial pH ($P < .001$, $P \leq .02$). All predelivery time intervals (operative room to delivery, spinal to skin, spinal to delivery, and uterine incision to delivery) increased as umbilical arterial pH interval decreased ($P < .05$ for all). In a stepwise linear regression, maternal body mass index, noncephalic presentation, spinal start to delivery interval, uterine incision to delivery interval, and maximum reduction in blood pressure from baseline were predictive of decreasing umbilical arterial pH after controlling for confounding variables ($F [5,442] = 17.7$, $P = .0001$], adjusted R^2 of 0.157. When evaluated by spinal to delivery time, both umbilical arterial and venous pH and partial pressure of carbon dioxide decreased ($P < .001$ for all), but base deficit and neonatal outcomes were similar ($P \geq .7$ for all). There were 2 cases of hypoxic-ischemic encephalopathy (0.38%). A receiver-operating characteristic curve demonstrated that a spinal start to delivery time greater than 27 minutes was associated with an umbilical arterial pH <7.1 (area under the curve, 0.74, 100% sensitivity, 21% specificity), and an interval greater than 30 minutes was associated with an umbilical arterial pH <7.0 (area under the curve, 0.80, 100% sensitivity, 33% specificity).

CONCLUSION: Longer spinal-to-delivery and uterine incision—to-delivery time intervals were associated with decreasing umbilical arterial pH at scheduled term cesarean delivery. Efforts to minimize predelivery time following spinal placement could reduce the frequency of unanticipated neonatal acidemia.

Key words: cesarean, hypotension, obesity, time interval, umbilical arterial pH

Maternal risks of cesarean delivery are well documented, but risks to the fetus are often overlooked.[1] Although rare, unexpected neonatal depression and hypoxic ischemic encephalopathy can occur during nonemergent cesarean delivery and may not be included in preoperative patient counseling.[1,2] With approximately one third of deliveries in the United States being performed by cesarean,[3] a more complete understanding of factors that can lead to adverse fetal outcomes is needed.

Neuraxial anesthesia-related hypotension and maternal obesity contribute to neonatal and umbilical arterial pH depression by reducing uterine perfusion at cesarean delivery.[4,5] Obese women have lower umbilical arterial pH at cesarean delivery than lean women.[4] Although some have hypothesized that the weight of the abdominal wall further reduces uterine perfusion in a supine obese patient awaiting cesarean delivery, the influence of intracorporeal uterine compression in obese patients remains poorly understood.[5]

Intraoperative hypotension alone has been reported to independently predict lower neonatal umbilical arterial pH after controlling for maternal obesity.[5] These factors may compound one another because obese women undergoing cesarean delivery have been shown to have greater incidence of intraoperative hypotension.[6,7]

After spinal placement, the fetus awaiting cesarean delivery is vulnerable to the influences of spinal-induced maternal hypotension and supine positioning, without surgeon awareness of fetal status. The duration of fetal exposure to the intrauterine environment is influenced by a summation of steps that include administration of adequate anesthesia, preoperative preparation, and accessing the uterus.

Cite this article as: Rimsza RR, Perez WM, Babbar S, et al. Time from neuraxial anesthesia placement to delivery is inversely proportional to umbilical arterial cord pH at scheduled cesarean delivery. Am J Obstet Gynecol 2019;220:389.e1-9.

0002-9378/$36.00

https://doi.org/10.1016/j.ajog.2019.01.006

AJOG at a Glance

Why was this study conducted?
Our purpose was to evaluate the association between predelivery time intervals and neonatal umbilical arterial pH at scheduled term cesarean delivery.

Key findings
Patients with longer predelivery time intervals had lower neonatal umbilical arterial pH.

What does this add to what is known?
Umbilical arterial pH is an indicator of neonatal metabolic status. Previous studies have identified intraoperative hypotension and maternal obesity as contributors to uterine hypoperfusion and decreased umbilical arterial pH at cesarean delivery. Between placement of neuraxial block and delivery, the fetus may be exposed to a hypoperfused uterine environment without surgeon awareness of fetal compromise. This study demonstrates that longer predelivery times, specifically the time from regional anesthesia placement and infant delivery, are associated with a decreased umbilical arterial pH and identifies an interval after which there is a greater likelihood of a lower umbilical arterial pH.

If predelivery time intervals serve as markers of exposure to risk factors for neonatal acidemia, minimizing duration of exposure during these periods may decrease the incidence of unanticipated neonatal depression. Although surgeons work to minimize skin incision to delivery time, they may overlook the preceding time of unknown fetal status between spinal placement and skin incision.[8] To fully assess fetal well-being prior to delivery, an interval including all time from neuraxial anesthesia administration to delivery should be evaluated.

Umbilical cord gas analytes are routinely performed in some centers to assess intrauterine fetal metabolic status at delivery.[9,10] Umbilical arterial gas analytes, along with the neonatal response to resuscitation, are used to predict the risk of neonatal hypoxic-ischemic encephalopathy.[11,12] We sought to evaluate neonatal umbilical arterial pH according to predelivery time intervals at scheduled term cesarean delivery. We hypothesized that duration of fetal exposure to the predelivery uterine environment influences neonatal umbilical arterial pH and that a longer nonmonitored interval between neuraxial anesthesia placement and delivery places the fetus at risk for neonatal metabolic depression.

Materials and Methods

We performed a retrospective cohort study of cesarean deliveries at an academic tertiary care institution between September 2014 and February 2017. We identified cases via electronic medical record query and then performed individual chart review for study eligibility and data collection. We included scheduled cesarean deliveries of singleton fetuses performed under spinal anesthesia between $37^{0/7}$ and $41^{0/7}$ weeks' gestation. Each patient had a reassuring non−stress test prior to delivery.

Exclusion criteria included labor, planned additional surgery (cesarean hysterectomy, adnexal surgery), major fetal anomalies, and anesthesia methods other than spinal. We perform universal umbilical cord gas analysis of venous and arterial samples in a point-of-care manner immediately following delivery. We excluded cases if umbilical cord gas analytes were unavailable or if time documentation was incomplete.

We collected demographic information and included those with hypertensive disorders and diabetes because these are common conditions in our population. Prior to performing the study, institutional review board approval was obtained (number 28035).

We analyzed maternal blood pressure from hospital admission to delivery because systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP = 2/3 DBP + 1/3 SBP). A MAP of 60−100 mm Hg is reported to be the minimum value necessary for vital organ perfusion outside pregnancy, although pregnant patients can have normal perfusion at lower values.[13]

We defined baseline blood pressure as the last value obtained prior to entering the operative suite. We calculated the change in blood pressure as the difference between baseline and the lowest recording before delivery. We defined mild hypotension as at least 20% decrease in SBP or MAP from baseline[14] and severe hypotension as at least 40% decrease from baseline. We recorded frequency and dose of vasopressor administration.

The patients in this study received routine institutional anesthesia care. Women undergoing cesarean delivery receive a 1 L crystalloid intravenous preload bolus within the 30 minutes preceding spinal anesthesia placement. Certified nurse anesthetists place neuraxial anesthesia under the supervision of anesthesiologists. A 25-gauge pencil-point spinal needle is used to access the spinal space at the level of L3−L4 or L4−L5. Upon return of cerebrospinal fluid, patients receive an intrathecal injection of 13.5 mg hyperbaric bupivacaine and 10 μg fentanyl. Anesthesia level to the L4 dermatome is confirmed.

Blood pressure is evaluated every 2 minutes from spinal placement until delivery. Phenylephrine is the agent of choice for spinal-induced hypotension, and ephedrine is reserved for second line treatment. Prophylactic vasopressor doses or continuous vasopressor infusions are performed at the discretion of the individual anesthesia provider but are not routine. Following spinal blockade, patients are placed in the supine position with left lateral tilt. Bed extenders and self-retaining panniculus retractors are placed if needed. Fetal heart rate is auscultated prior to sterile skin preparation and catheter placement. The surgical team included 2 residents and an attending physician.

The primary outcome was umbilical arterial pH. We analyzed patient characteristics, blood pressure outcomes,

TABLE 1
Demographic and intrapartum data at scheduled cesarean delivery by neonatal umbilical arterial pH interval

Umbilical arterial pH	<7.00	7.01–7.10	7.11–7.20	7.21–7.30	>7.30	
n, total = 527	6	15	53	336	117	*P* value
Maternal characteristics						
Age, y	30 ± 5	31 ± 6	30 ± 5	29 ± 6	29 ± 5	.50
Body mass index, kg/m^2	46 ± 9	42 ± 7	41 ± 9	36 ± 9	34 ± 6	< .001
Parity, n	2 ± 2	1 ± 1	2 ± 1	2 ± 1	2 ± 1	.20
Prior cesarean delivery	4 (67)	11 (73)	44 (83)	277 (82)	98 (84)	.70
Race						
Non-Hispanic white	1 (17)	5 (33)	13 (25)	103 (31)	54 (46)	.02
Non-Hispanic black	5 (83)	10 (67)	39 (74)	208 (62)	59 (50)	.03
Hypertensive disorder	2 (33)	4 (27)	10 (19)	42 (13)	16 (14)	.20
Maternal diabetes	2 (33)	7 (47)	12 (23)	51 (15)	16 (14)	.009
Intrapartum findings						
Self-retaining retractor use	2 (33)	2 (13)	5 (9)	26 (8)	2 (2)	.01
Noncephalic presentation	2 (33)	6 (40)	12 (23)	39 (12)	8 (7)	< .001
Measured blood loss, mL	1250 ± 900	1150 ± 720	920 ± 430	800 ± 430	780 ± 430	.002
Birthweight, g	3730 ± 425	3720 ± 740	3560 ± 580	3330 ± 530	3340 ± 490	.001
Procedure intervals, min						
Total operative room time	124 ± 31	110 ± 25	105 ± 28	94 ± 21	94 ± 25	< .001
Operative room entry to delivery	56 ± 24	42 ± 6	41 ± 14	38 ± 10	37 ± 11	< .001
Spinal start to delivery	54 ± 23	40 ± 6	39 ± 12	35 ± 10	34 ± 10	< .001
Spinal stop to delivery	36 ± 11	33± 6	32 ± 9	29 ± 9	28 ± 9	.006
Spinal procedure time	17 ± 21	7 ± 4	7 ± 6	6 ± 4	6 ± 6	< .001
Spinal start to skin incision	38 ± 23	24 ± 4	25 ± 9	21 ± 5	21 ± 6	< .001
Spinal stop to skin incision	18 ± 3	16 ± 3	17 ± 5	15 ± 4	15 ± 3	.002
Skin incision to delivery	18 ± 10	17 ± 6	16 ± 8	14 ± 8	12 ± 7	.040
Uterine incision to delivery	3 ± 2	3 ± 3	2 ± 1	1 ± 1	1 ± 1	< .001

Data are presented as n (percentage), mean ± SD, or median (interquartile range).

Rimsza et al. Anesthesia to delivery time intervals and neonatal umbilical arterial pH. Am J Obstet Gynecol 2019.

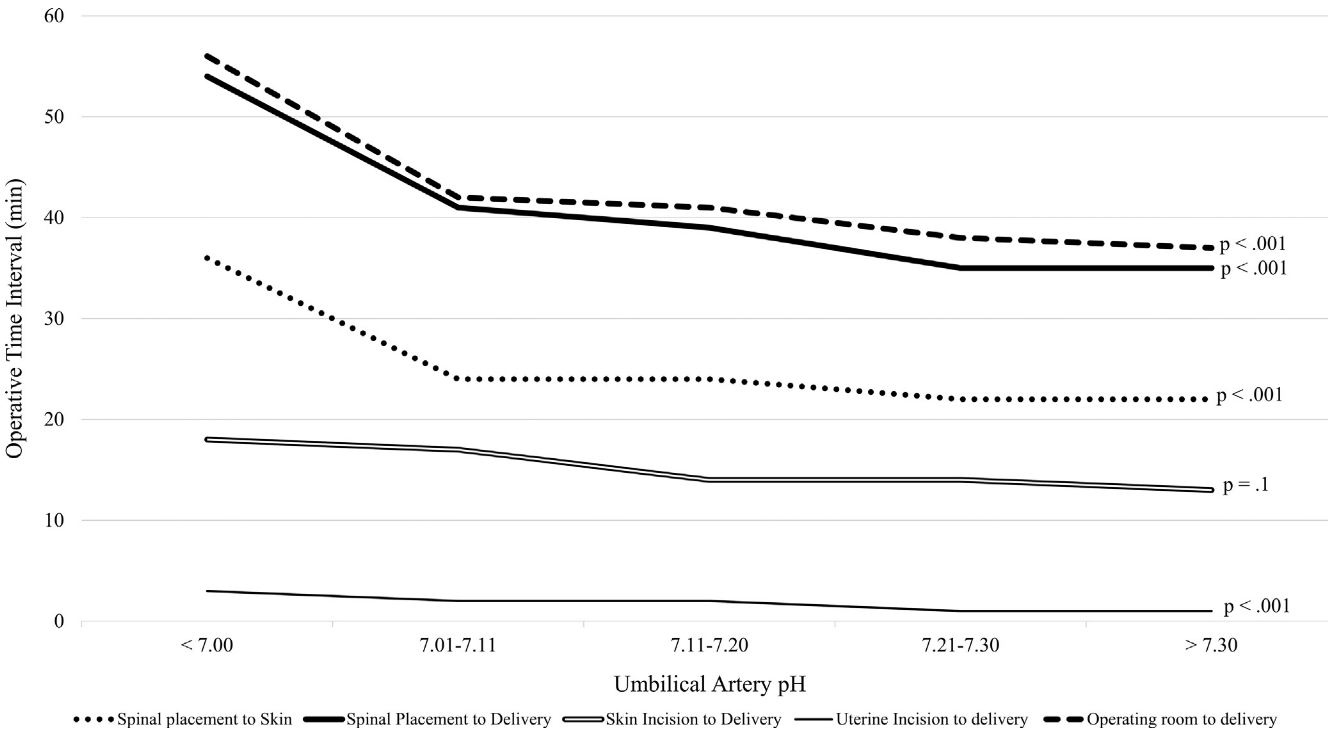
and predelivery time intervals according to the umbilical arterial pH intervals of <7.0, 7.01–7.10, 7.11–7.20, 7.21–7.30, and >7.30. We calculated time intervals between individual time points (operating room [OR] entry, spinal start, spinal stop, skin incision, uterine incision, delivery of infant, and operating room exit).

We performed a stepwise linear regression to identify factors predictive of decreasing umbilical arterial pH. We then analyzed umbilical arterial and venous cord gas analytes (pH, partial pressure of carbon dioxide [pCO_2], and base deficit), the incidence of abnormal analytes (umbilical arterial pH <7.1, 7.0, or base deficit >12 mEq/L), and neonatal outcomes (neonatal intensive care unit admission, respiratory insufficiency, hypoxic-ischemic encephalopathy, neonatal death, Apgar scores, incidence of 5 minute Apgar <7), according to the duration of the interval from start spinal to delivery, in 20 minute increments.

We calculated a receiver-operator characteristic curve to identify a predelivery time interval associated with abnormal umbilical arterial pH. A normal neonatal umbilical arterial pH is considered greater than 7.20.[4] Definitions of abnormal umbilical cord pH vary, but we assert that in a scheduled cesarean delivery with reassuring preoperative fetal testing, no amount of neonatal depression should be considered normal.[9,10] We therefore calculated receiver-operator characteristic curves for the predelivery time interval and arterial pH values below 7.1 and 7.0.[9,10]

We analyzed data using SPSS statistical software (version 25, 2017; SPSS Inc, Armonk, NY). We compared continuous variables using an analysis of variance,

FIGURE 1
Cesarean predelivery time intervals and neonatal umbilical artery pH



Rimsza et al. Anesthesia to delivery time intervals and neonatal umbilical arterial pH. Am J Obstet Gynecol 2019.

categorical values using χ^2 test, and ordinal and nonnormally distributed data using Kruskal-Wallis test. A value of $P < .05$ was considered significant.

Results

Of 711 patients delivered by scheduled cesarean during the study interval, 527 patients met study criteria and were analyzed. Of the 184 excluded patients, 43 had gestation less than 37 weeks, 47 had an anesthesia method other than spinal blockade, 31 were missing umbilical arterial pH, 40 lacked time interval data, 10 had additional planned surgery, 8 had major fetal anomalies, and 5 presented in labor. Indications for delivery between $37^{0/7}$ and $38^{6/7}$ included placenta previa, prior classical cesarean incision or myomectomy, and hypertensive disorders of pregnancy.

Maternal demographic data, intrapartum findings, and time intervals are presented according to umbilical arterial pH interval in Table 1. The cohort was 61% African American, 71% government insured, 14% hypertensive, 17% diabetic, and 39% with 2 or more prior cesarean deliveries. The median umbilical arterial pH was 7.27 (interquartile range, 7.23—7.29), with a minimum pH of 6.61 and a maximum of 7.38.

The median body mass index (BMI) was 35.1 kg/m^2 (interquartile range, 30.3—41.3). BMI significantly increased with decreasing umbilical arterial pH ($P < .001$). African-American and diabetic patients had lower umbilical arterial pH ($P = .03$ and $P = .009$, respectively), while parity ($P = .2$) and hypertensive disorders ($P = .2$) were similar.

Delivery from noncephalic (breech or transverse) presentation occurred in 13% of cases and was more frequent with decreasing umbilical arterial pH ($P < .001$). Mean birthweight was 3370 $\pm$ 540 g, and birthweights were higher as umbilical arterial pH decreased ($P = .001$).

Total OR, OR to delivery, start spinal to skin incision, start and stop spinal to delivery, skin to delivery, and uterine incision to delivery time intervals all increased with decreasing umbilical arterial pH interval ($P < .05$ for all; Table 1). Figure 1 demonstrates trends in predelivery time intervals according to umbilical arterial pH.

Blood pressure and vasopressor administration data are presented according to umbilical arterial pH interval in Table 2. Baseline blood pressures were similar, but the lowest recorded blood pressures (minimum SBP, DBP, MAP) were lower ($P \leq .02$ for all) and the greatest reductions in blood pressure from baseline (ΔSBP, ΔDBP, ΔMAP) were larger ($P \leq .008$ for all) with decreasing umbilical arterial pH. Although incidence of a 20% MAP decrease was common across groups ($P = .06$), women with a 40% MAP decrease from baseline had lower pH values ($P = .003$). The mean phenylephrine dose was higher, and likelihood of receiving ephedrine was greater, among those with lower umbilical arterial pH ($P = .02$, $P < .001$).

In a stepwise linear regression, maternal BMI, noncephalic presentation,

TABLE 2
Predelivery blood pressures and vasopressor administration at scheduled cesarean delivery by neonatal umbilical arterial pH interval

Umbilical Arterial pH	<7.00	7.01–7.10	7.11–7.20	7.21–7.30	>7.30	
n, total = 527	6	15	53	336	117	*P* value
Baseline, mm Hg						
SBP	128 ± 11	133 ± 17	129 ± 13	125 ± 13	125 ± 11	.070
DBP	78 ± 10	76 ± 14	75 ± 9	73 ± 10	74 ± 9	.700
MAP	95 ± 9	95 ± 13	93 ± 9	91 ± 10	90 ± 9	.200
Minimum pressure, mm Hg						
SBP	77 ± 19	91 ± 17	89 ± 15	90 ± 15	94 ± 14	.020
DPB	35 ± 8	35 ± 9	37 ± 10	40 ± 10	42 ± 11	.020
MAP	49 ± 11	53 ± 10	54 ± 9	57 ± 10	59 ± 10	.010
Largest pressure decrease, mm Hg						
⊿SBP	−51 ± 28	−42 ± 26	−41 ± 13	−36 ± 16	−32 ± 14	.002
⊿DBP	−43 ± 9	−41 ± 17	−37 ± 11	−34 ± 12	−33 ± 12	.008
⊿MAP	−46 ± 15	−41 ± 18	−39 ± 10	−34 ± 12	−33 ± 12	.001
Hypotensive episodes						
SBP decrease >20%	6 (100)	10 (67)	46 (92)	245 (77)	78 (72)	.030
SBP decrease >40%	2 (33)	6 (40)	7 (14)	45 (15)	6 (6)	.002
⊿MAP decrease >20%	6 (100)	14 (93)	51 (100)	310 (93)	100 (88)	.060
⊿MAP decrease >40%	4 (67)	9 (60)	30 (59)	138 (42)	34 (30)	.003
Vasopressor administration						
Phenylephrine use	6 (100)	13 (93)	50 (98)	296 (90)	105 (91)	.400
Phenylephrine dose, μg	1640 ± 1540	1390 ± 1520	990 ± 860	860 ± 770	810 ± 780	.020
Epinephrine use	4 (67)	3 (20)	4 (8)	6 (2)	1 (1)	< .001
Ephedrine dose, mg	40 ± 15	50 ± 0	45 ± 15	40 ± 10	50 ± 0	.700

Data are presented as n (percentage) or mean ±SD.

SBP, systolic blood pressure; *DBP*, diastolic blood pressure; *MAP*, mean arterial pressure.

Rimsza et al. Anesthesia to delivery time intervals and neonatal umbilical arterial pH. Am J Obstet Gynecol 2019.

spinal start to delivery interval, uterine incision to delivery interval, and maximum reduction in blood pressure from baseline (⊿MAP), were predictive of decreasing umbilical arterial pH after controlling for confounders (F [5,442] = 17.7, $P = .0001$], adjusted R^2 of 0.157. Variables included in the model that were not predictive of decreasing pH were maternal diabetes, spinal stop to delivery time, and phenylephrine dose.

Noncephalic fetal presentation predicted a decline in umbilical arterial pH of 0.132. Umbilical arterial pH decreased by 0.142 for each minute from uterine incision to delivery and 0.139 for each minute from spinal placement to delivery. Each unit increase in maternal BMI (kilograms per square meter) resulted in an umbilical arterial pH reduction of 0.142, and each unit decline in MAP (millimeters of mercury) resulted in an umbilical arterial pH decrease of 0.153.

Umbilical arterial and venous cord gas analytes and neonatal outcomes are presented in Table 3, according to increasing time from spinal to delivery. The overall incidence of umbilical arterial pH <7.1 was 4.0% (21 of 527) and the incidence of pH <7.0 was 1.1% (6 of 527).

Mean arterial and venous pH were lower and pCO_2 values were higher at longer spinal to delivery times ($P < .001$ for both). Umbilical arterial pH <7.0 was more common as spinal-to-delivery time increased ($P = .001$). Neonatal intensive care unit admission, 1 and 5 minute Apgar score, and incidence of Apgar score below 5 minutes were similar among groups ($P > .05$ for all).

Of 527 cesarean deliveries, there were 2 cases of hypoxic-ischemic encephalopathy. One case was a 35 year old G3P2002 at 39 weeks with 2 prior cesareans whose delivery was complicated by a BMI of 57 kg/m^2 and severe adhesive disease. MAP dropped 40% below baseline despite 3600 μg of phenylephrine and 20 mg of epinephrine. Spinal-to-delivery time was 87 minutes and

TABLE 3
Umbilical cord gas analytes and neonatal outcomes at scheduled cesarean delivery by spinal start to delivery time interval

Spinal to delivery interval, min	<20	20–39	40–59	≥60	
n = 527	14	388	105	20	*P* value
Arterial analytes					
pH	7.28 ± .03	7.25 ± .06	7.24 ± .08	7.20 ± .17	< .001
pCO_2	52 ± 6	57 ± 9	59 ± 11	64 ± 20	< .001
Base deficit	3 ± 2	3 ± 2	3 ± 3	4 ± 4	.900
Venous analytes					
pH	7.33 ± .03	7.31 ± .06	7.30 ± .06	7.24 ± .15	< .001
pCO_2	45 ± 3	46 ± 8	48 ± 8	57 ± 20	< .001
Base deficit	3 ± 1	4 ± 2	4 ± 2	4 ± 4	.200
Abnormal arterial analytes					
pH <7.1	—	11 (3)	8 (8)	2 (10)	.060
pH <7.0	—	2 (0.5)	2 (2)	2 (10)	.001
Base deficit >12	—	3 (1)	2 (2)	1 (5)	.300
Neonatal outcomes					
Neonatal intensive care unit	1 (7)	49 (13)	16 (15)	3 (15)	.800
Respiratory complications	1 (7)	44 (11)	12 (11)	4 (20)	.700
Hypoxemic-ischemic encephalopathy	—	1 (0.3)	—	1 (5)	—
Apgar score, 1 min	8 (8,9)	8 (8,9)	8 (7,8)	8 (6,8)	.070
Apgar score, 5 min	9 (9,9)	9 (9,9)	9 (9,9)	9 (9,9)	.400
5 min Apgar <7	—	6 (2)	2 (2)	1 (5)	.700

Data presented as n (percentage), mean ± SD, and median (interquartile range).

pCO_2, partial pressure of carbon dioxide.

Rimsza et al. Anesthesia to delivery time intervals and neonatal umbilical arterial pH. Am J Obstet Gynecol 2019.

uterine incision to delivery time was 2 minutes. Umbilical arterial analytes were pH of 6.62, pCO_2 of 130 mmol/L, and base deficit incalculable.

The second case was a 24 year old primigravida with a BMI of 49 kg/m^2, who underwent primary cesarean at 37 weeks because of breech presentation and preeclampsia. MAP dropped 40% despite 800 μg of phenylephrine and 50 mg of epinephrine. Spinal placement to delivery time was 37 minutes and uterine incision to delivery time was 1 minute. Umbilical arterial analytes were pH of 6.70, pCO_2 of 129 mmol/L, and base deficit of 24 mEq/L. There were no cases of neonatal demise.

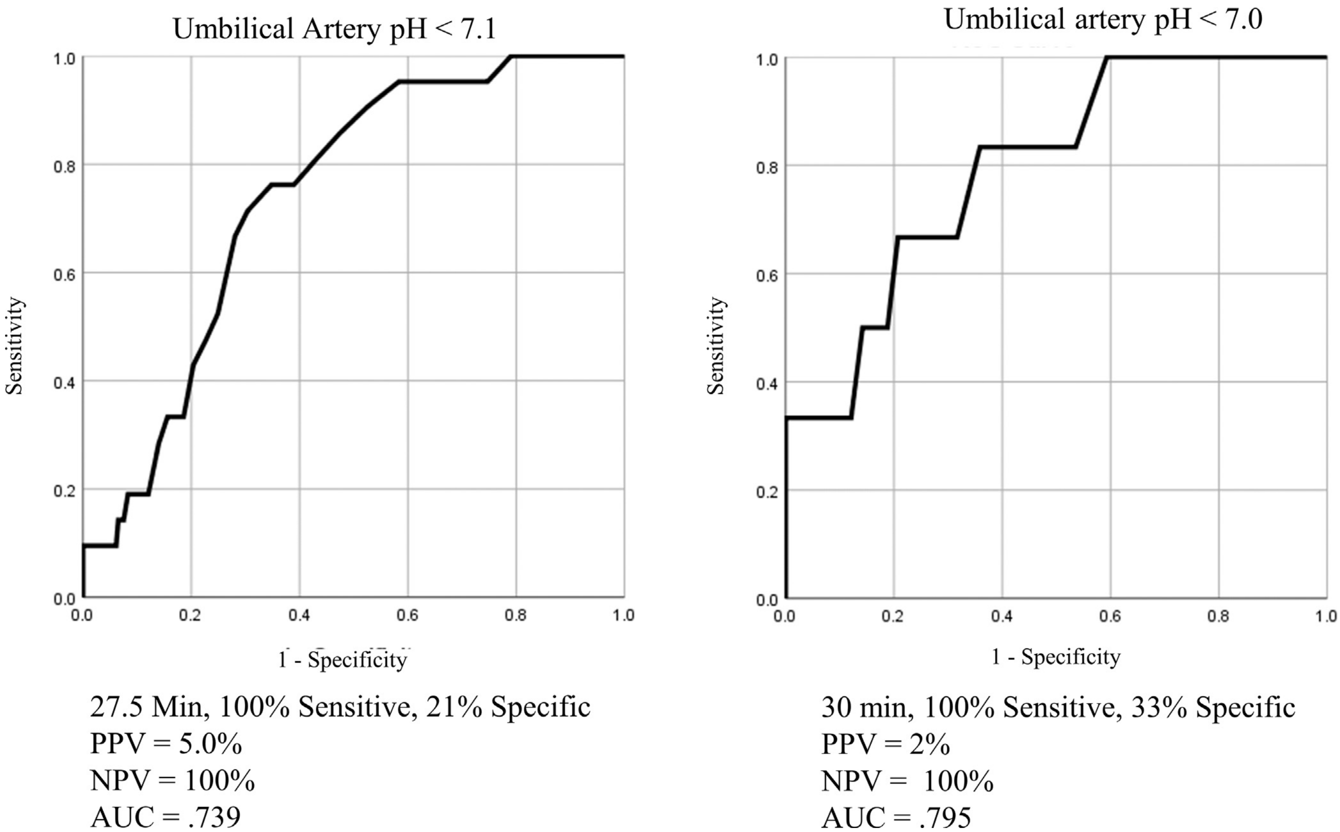
Receiver-operating characteristic curves demonstrated that spinal start to delivery time greater than 27 minutes predicted an umbilical arterial pH <7.1 with 100% sensitivity and 21% specificity (area under the curve, 0.74) with a positive predictive value of 5% and a negative predictive value of 100%. Spinal start-to-delivery time greater than 30 minutes predicted an umbilical arterial pH <7.0 with 100% sensitivity and 33% specificity (area under the curve, 0.79) with a positive predictive value of 2% and a negative predictive value of 100% (Figure 2).

Comment

We found that longer predelivery times were associated with decreasing neonatal umbilical arterial pH at scheduled term cesarean delivery. Maternal obesity, noncephalic fetus, spinal start-to-delivery time, uterine incision-to-delivery time, and maternal hypotension were predictive of decreasing umbilical arterial pH. Cases with longer spinal start-to-delivery time had lower umbilical arterial and venous pH, increased pCO_2, and greater frequency of pH <7.0. Delivery within 27 minutes of spinal start was associated with umbilical arterial pH >7.1, and delivery within 30 minutes was associated with umbilical arterial pH >7.0.

Our finding of a 0.38% incidence of unanticipated hypoxemic ischemic encephalopathy is consistent with previously published reports of 0–0.36% incidence at scheduled term cesarean delivery.[15] Our finding of a 4.0% incidence of umbilical arterial pH <7.1 is also consistent with prior studies that reported umbilical arterial pH <7.1 in 2-5% of cases.[4,5] Arterial and venous pH decreased, and pCO2 increased, with longer predelivery time, consistent with respiratory acidemia.

FIGURE 2
Receiver-operator characteristic curves, spinal start to delivery time, and neonatal umbilical arterial pH at schedule cesarean delivery



Rimsza et al. Anesthesia to delivery time intervals and neonatal umbilical arterial pH. Am J Obstet Gynecol 2019.

The infrequency of abnormalities in base deficit suggests that in a smaller proportion of patients, this progressed to a metabolic acidemia.[16]

Obesity increases both presurgical preparation and operative time

We believe that the high prevalence of obesity in our cohort prolonged both presurgical preparation and predelivery operative time. In the United States, 28% of women are obese prior to pregnancy, and obese women are more likely to be delivered by cesarean.[17,18]

Preparing the obese woman for surgical delivery can involve additional steps, including longer antiseptic skin preparation, placement of bed extenders, securing self-retaining panniculus retractors, and patient positioning.[19] Greater surgical dissection time to access the uterus is often needed in obese women because of adhesion formation from prior cesarean deliveries and increased subcutaneous adipose tissue depth.[8,20]

From the time of spinal placement to delivery, the fetus is vulnerable to the effects of maternal hypotension and supine positioning. While intended to improve operative exposure and reduce infectious morbidity, these additional preparatory steps result in a longer duration of time without fetal monitoring. Previous investigators have proposed that internal compressive forces in obese patients may further impair uterine perfusion.[4] Given that understanding of this relationship remains limited at present, the duration of fetal exposure to the uterine environment may be the most useful and modifiable risk factor.

Spinal-induced hypotension in obesity

Hypotension and maternal BMI were each independently associated with reduced umbilical arterial pH in our cohort. This finding is consistent with prior studies that demonstrate greater severity of spinal-associated hypotension for obese women.[6,21]

Both absolute maternal hypotension and a decrease in blood pressure from baseline can reduce uterine perfusion.[22] Although women commonly receive vasopressors to maintain vascular tone after neuraxial anesthesia, hypotension remains a common complication of spinal anesthesia and prolonged fetal exposure to this environment reduces neonatal umbilical cord pH.[5]

We evaluated both spinal start-to-delivery time and spinal stop-to-delivery time and found that only the spinal start to delivery interval was predictive of decreasing umbilical arterial pH. In cases of uncomplicated spinal placement, the spinal procedure time is minimal. We hypothesize that in cases of complicated spinal placement, multiple placement attempts could result in some delivery of local anesthetic that could influence maternal blood pressure, even if complete spinal blockade is not achieved.

Prolonged uterine incision to delivery interval

Noncephalic fetal presentation and uterine incision to delivery time predicted lower umbilical arterial pH in our cohort. With uterine incision, the uterus begins to contract and blood flow to the fetus diminishes rapidly.[23] Additional maneuvers may be required to deliver the noncephalic fetus, increasing the duration of exposure to a hypoperfused environment.[23] Our finding that birthweight increased with decreasing umbilical arterial pH is also consistent with prior findings that larger infants may require additional maneuvers for successful delivery, increasing the duration of fetal hypoperfusion.

Strengths and limitations

To our knowledge, no previous studies have evaluated fetal acid base status in the context of predelivery time intervals. The main strength of this study is the identification of an easily measurable time interval with high sensitivity for fetal arterial pH depression. While other contributors to neonatal umbilical pH can be difficult to quantify, the time intervals represent additive duration of these influences and provide a meaningful threshold to guide clinical management. Our diverse patient population with multiple comorbidities makes our findings applicable to a high-risk obstetric population. Our study was not performed with routine use of continuous vasopressor infusion, a practice that can attenuate spinal-induced hypotension.[24–28] Our findings contribute to an understanding of neonatal outcomes using conventional approaches to hypotension management.

This study was limited in its ability to evaluate infrequent outcomes. A larger sample size would be needed to primarily investigate the incidence of hypoxemic-ischemic encephalopathy. We did not collect long-term neonatal outcomes to determine whether the effects of a low umbilical arterial pH lasted beyond the neonatal intensive care unit admission. We also did not evaluate the time, duration, or status of the post-spinal fetal monitoring, limiting our ability to identify those patients who were delivered more rapidly because of surgeon awareness of a nonreassuring fetal heart rate. The retrospective design limits our ability to control for other potential contributors and introduces the errors inherent in chart reviews.

Conclusion

Delivery within 30 minutes of spinal placement reduces the risk of an umbilical arterial pH <7.0. While maternal obesity and adhesive disease are a reality of contemporary obstetrics, a team-based approach to minimizing preparatory times within the control of the surgical team could reduce fetal risk. Beginning with the time of spinal placement, incorporation of time tracking with verbally announced cues could help the surgical team optimize efficiency and reduce unnecessary delay in predelivery preparation. Further studies are needed to determine whether institutional guidelines for minimizing time from spinal placement to delivery will improve neonatal outcomes. ■

References

1. American College of Obstetricians and Gynecologists. Vaginal birth after cesarean delivery. ACOG Practice bulletin no. 184. Obstet Gynecol 2017;130:e217–33.
2. Vidic Z, Blickstein I, Stucin Gantar I, Verdenik I, Tul N. Timing of elective cesarean section and neonatal morbidity: a population-based study. J Matern Fetal Neonatal Med 2016;29:2461–3.
3. Martin JA, Hamilton BE, Sutton PD, et al. Births: final data for 2006. Natl Vital Stat Rep 2009;57:1–104.
4. Powell MF, Morgan CJ, Cantu JA, et al. Obesity and neonatal cord blood gas results at cesarean: effect of intraoperative blood pressure. Am J Perinatol 2017;34:716–22.
5. Edwards RK, Cantu J, Cliver S, Biggio JR, Owen J, Tita AT. The association of maternal obesity with fetal pH and base deficit at cesarean delivery. Obstet Gynecol 2013;122:262–72.
6. Vricella LK, Louis JM, Mercer BM, Bolden N. Impact of morbid obesity on epidural anesthesia complications in labor. Am J Obstet Gynecol 2011;205:370.e1–6.
7. Danilenko-Dixon DR, Tefft L, Cohen RA, Haydon B, Carpenter MW. Positional effects of maternal cardiac output during labor with epidural analgesia. Am J Obstet Gynecol 1996;175(4 Pt 1):867–72.
8. Girsen AI, Osmundson SS, Naqvi M, Garabedian MJ, Lyell DJ. Body mass index and operative times at cesarean delivery. Obstet Gynecol 2014;124:684–9.
9. Yeh P, Emary K, Impey L. The relationship between umbilical cord arterial pH and serious adverse neonatal outcome: analysis of 51,519 consecutive validated samples. BJOG 2012;119:824–31.
10. Andres RL, Saade G, Gilstrap LC, et al. Association between umbilical blood gas parameters and neonatal morbidity and death in neonates with pathologic fetal acidemia. Am J Obstet Gynecol 1999;181:867–71.
11. White CR, Doherty DA, Henderson JJ, Kohan R, Newnham JP, Pennell CE. Accurate prediction of hypoxic-ischemic encephalopathy at delivery: a cohort study. J Matern Fetal Neonatal Med 2012;25:1653–9.
12. Cantu J, Szychowski JM, Li X, et al. Predicting fetal acidemia using umbilical venous cord gas parameters. Obstet Gynecol 2014;124:926–32.
13. Walsh M, Deveraux PJ, Garg AX, et al. Relationship between intraoperative mean arterial pressure and clinical outcomes after noncardiac surgery: toward an empirical definition of hypotension. Anesthesiology 2013;119:507–15.
14. Salmasi V, Maheshwari K, Yang D, et al. Relationship between intraoperative hypotension, defined by either reduction from baseline or absolute threshold, and acute kidney and myocardial injury after noncardiac surgery: a retrospective cohort analysis. Anesthesiology 2017;126:47–65.
15. Guise JM, Eden K, Emeis C, et al. Vaginal birth after cesarean: new insights. Evidence report/technology assessment no. 191. AHRQ Publication No. 10–E003. Rockville (MD): Agency for Healthcare Research and Quality; 2010.
16. Bobrow CS, Soothill PW. Causes and consequences of fetal acidosis. Arch Dis Child Fetal Neonatal Ed 1999;80:F2469.
17. Gregor L, Remington PL, Lindberg S, Ehrenthal D. Prevalence of pre-pregnancy obesity, 2011-2014. WMJ 2016;115:228–32.
18. Chu SY, Kim SY, Schmid CH, et al. Maternal obesity and risk of cesarean delivery: a meta-analysis. Obes Rev 2007;8:385–94.
19. American College of Obstetricians and Gynecologists. Gynecologic surgery in the obese woman. ACOG Committee opinion no. 619. Obstet Gynecol 2015;125:274–8.
20. Rossouw JN, Hall D, Harvey J. Time between skin incision and delivery during cesarean. Int J Gynaecol Obstet 2013;121:82–5.
21. Bamgbade OA, Khalaf WM, Ajai O, Sharma R, Chidambaram V, Madhavan G. Obstetric anesthesia outcome in obese and non-obese parturients undergoing cesarean delivery: an observational study. Int J Obstet Anesth 2009;18:221–5.
22. Maayan-Metzger A, Schushan-Eisen I, Todris L, Etchin A, Kuint J. Maternal hypotension during elective cesarean section and short-term

neonatal outcome. Am J Obstet Gynecol 2010;202:56.e1–5.
23. Bader AM, Datta S, Arthur GR, Benvenuti E, Courtney M, Hauch M. Maternal and fetal catecholamine and uterine incision-to-delivery interval during elective cesarean section. Obstet Gynecol 1990;75:600–3.
24. Mohta M, Duggal S, Chilkoti GT. Randomized double-blind comparison of bolus phenylephrine or ephedrine for treatment of hypotension in women with pre-eclampsia undergoing cesarean section. Anesthesia 2018;73:839–46.
25. Gunusen I, Karaman S, Ertugrul V, First V. Effects of fluid preload (crystalloid or colloid) compared with crystalloid co-load plus ephedrine infusion on hypotension and neonatal outcome during spinal anaesthesia for cesarean delivery. Anaesth Intensive Care 2010;38:647–53.
26. Onwochei DN, Ngan Kee WD, Fung L, Downey K, Ye XY, Carvalho JCA. Norepinephrine intermittent intravenous boluses to prevent hypotension during spinal anesthesia for cesarean delivery: A sequential allocation dose-finding study. Anesth Analg 2017;125:212–8.
27. Ngan Kee WD, Khaw KS, Ng FF, Lee BB. Prophylactic phenylephrine infusion for preventing hypotension during spinal anesthesia for cesarean delivery. Anesth Analg 2004;98:815–21.
28. Ngan Kee WD, Khaw KS, Ng FF. Prevention of hypotension during spinal anesthesia for cesarean delivery: an effective technique using combination phenylephrine infusion and crystalloid cohydration. Anesthesiology 2005;103:744–50.

Author and article information

From the Division of Maternal-Fetal Medicine, Department of Obstetrics, Gynecology, and Women's Health, St Louis University School of Medicine, St Louis, MO (Drs Rimsza, Perez, Babbar, and Vricella); and the Department of General Surgery, University of Central Florida, Orlando, FL (Dr O'Brien).

Received Sept. 4, 2018; revised Dec. 18, 2018; accepted Jan. 2, 2019.

The authors report no conflict of interest.

Presented at the 85th annual meeting of the Central Association of Obstetrics and Gynecologists, Oct. 17—20, 2018, and awarded the Krantz Memorial Paper.

Corresponding author: Rebecca Rimsza, MD. Rebecca.Rimsza@health.slu.edu