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The Relationship Between Uterine Activity, Oxytocin Dosing, Labor Progress, and Mode of Birth in Nulliparas with Obesity: Minimal Usefulness of Montevideo Unit Measurement

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Abstract

Background: Maternal obesity and cesarean birth disproportionately affect Black parturients; thus, prevention of cesarean birth is a key modifiable factor to improve pregnancy outcomes and reduce disparities. The primary driver of unplanned cesarean birth among people with higher body mass index is prolonged labor duration. However, strategies to optimize outcomes in these situations have not been established. We aimed to evaluate the influence of oxytocin augmentation on uterine activity and labor progression in nulliparas with obesity. **Methods:** This secondary analysis involved nulliparas with obesity (BMI ≥30 kg/m^2) who had spontaneous labor onset followed by oxytocin augmentation and an intrauterine pressure catheter. Using Linear Mixed Models, we evaluated relationships between uterine activity measured in Montevideo units (MVU), oxytocin dose, and rate of cervical dilation normalized by labor duration. **Results:** In this diverse sample (35.6% Caucasian, 16.11% African American, 40.2% Hispanic) of nulliparas with obesity (n = 87; BMI 35.54 ± 4.38 kg/m^2), 31% ended labor with cesarean birth. Among those with vaginal birth, only 13% had MVU ≥200 prior to the final 2 hours of labor. MVUs were only minimally responsive to oxytocin dose and were not associated with labor progression nor birth route. **Conclusion:** MVU measurements may not be useful to diagnose labor arrest in nulliparas with obesity. Optimizing care for birthing people with obesity is essential for improving perinatal outcomes and for reducing racial health disparities.

Keywords

labor dystocia, uterine physiology, cesarean delivery, obesity, montevideo units, healthcare disparities

Introduction

Cesarean birth can be a lifesaving procedure and is a necessary element of safe maternity care; however, cesareans are also linked to maternal and fetal morbidity and increased risks for future pregnancies (Alkire et al., 2012; Keag et al., 2018). The World Health Organization calculated the optimal cesarean rate that balances these risks and benefits to be 10–15% (Office of Disease Prevention and Health Promotion, 2017), while others have calculated the optimal rate in the United States to be 20% (Zuarez-Easton et al., 2015). The United States set a goal to reduce the cesarean rate among low-risk women to 23.6% by 2020 (Office of Disease Prevention and Health Promotion, 2017; Transforming Maternity Care Vision et al., 2010). Despite multidisciplinary efforts, the U.S. cesarean birth rate in 2020 increased across all races and ethnicities, with continued evidence of large racial disparities in low-risk cesarean (30.6% among Black parturients compared to 24.9% among White parturients and 25.1% among Hispanic parturients) (Osterman et al., 2022).

Racial disparities also exist in maternal obesity, with downstream effects on perinatal outcomes (Andrikopoulou et al., 2022). 30% of all birthing people were obese in 2020 (BMI >30.0 kg/m^2), with significant racial/ethnic disparities (27.4%

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obesity among white pregnant people, compared to 40.3% in Black and 33.6% in Hispanic) (Osterman et al., 2022). Obesity increases people's risk for a broad range of perinatal complications (Wang et al., 2021), including post-term pregnancy (Halloran et al., 2012), prolonged labor (Kominiarek et al., 2011), unplanned cesarean birth (Poobalan et al., 2009), post-operative surgical complications (Stamilio & Scifres, 2014), and repeat cesarean birth (Caughey et al., 2014; Lowe, 2007). Optimizing intrapartum care for birthing people with obesity is essential to reduce the rates of perinatal complications and their longterm effects. Precision care of this population is a priority strategy to improve maternal child health in the United States and for addressing racial perinatal health disparities.

The most common indication for cesarean birth in the U.S. labor dystocia (Barber et al., 2011; Caughey et al., 2014), is also the primary means by which those with maternal obesity experience birth complications (Carlson et al., 2015; Chu et al., 2007). Labor dystocia is typically diagnosed when cervical dilation progresses more slowly than the 95th percentile rate (Friedman, 1954; Neal et al., 2015; Zhang et al., 2010). The standard treatment for labor dystocia consists of artificially rupturing the membranes, quantifying the strength of uterine activity using Montevideo Units (MVU), and augmenting contractions with synthetic oxytocin titrated to reach 200 MVU of uterine activity (Caughey et al., 2014). In an effort to decrease cesarean birth rates, the American College of Obstetricians and Gynecologists and the Society for Maternal Fetal Medicine recommend limiting the use of cesarean birth to cases of labor arrest during the active phase with no cervical dilation for at least 6 hours, despite oxytocin augmentation. However, if the clinician is able to verify uterine activity ≥200 MVU in the presence of oxytocin augmentation, they allowed that cesarean could be considered after only 4 hours with no cervical dilation (Caughey et al., 2014).

Although an integral part of labor dystocia clinical treatment guidelines, uterine activity thresholds are based on limited data, and their usefulness across laboring people of different BMI is unknown. For many years, 200 MVU has been considered the lowest threshold of uterine activity needed to achieve cervical dilation during induction and augmentation of labor (Caldeyro-Barcia et al., 1957; Caughey et al., 2014; Hauth et al., 1986). However, this value is based on a small 1986 study of 109 women that was never replicated (Hauth et al., 1986). More recent research has called into question the accuracy of the 200 MVU threshold and its clinical utility (Frey et al., 2018; Gee & Frey, 2020). Moreover, although several groups of investigators document a dose–response relationship between increasing body mass index (BMI) and slow labor progress (Carlson et al., 2015; Caughey et al., 2014), current literature has reported that the MVU threshold of 200 is only reached in about half of obese parturients when measured in the last 2 hours of active labor (Buhimschi et al., 2004; Chin et al., 2012; Hautakangas et al., 2022; Roloff et al., 2015). Data are not available earlier in active labor when dystocia is most common (Kominiarek et al., 2011) and the extent to which MVUs reflect uterine activity, labor progression, or oxytocin augmentation in people with obesity is limited. When labor dystocia occurs in this population, clinicians have little evidence on which to individualize their care by the laboring person's BMI, leading to overreliance on cesarean birth (Carlson & Lowe, 2014). Thus, the aim of this study was to characterize uterine activity, measured in Montevideo units (MVU), and the relationship between oxytocin doses, uterine activity, and labor progress in nulliparous parturients with obesity who had spontaneous onset of labor with augmentation.

Methods

We conducted a secondary analysis using data from a retrospective cohort study of 542 patients who gave birth at the UCHealth Hospital in Aurora, Colorado between October 1, 2005 and December 31, 2012 (Carlson et al., 2017a; Snowden & Klebanoff, 2022). The Colorado Multiple Institutional Review Board approved this study (Protocol #20-1746) and the parent study (Protocol #14-0557) as exempt (Carlson et al., 2017a).

Sample

Patients considered for inclusion in the parent study had obesity (BMI ≥30 kg/m^2) at the time of hospital admission, had no other medical or obstetric complications, were nulliparous, and experienced spontaneous labor onset with a singleton pregnancy. Parent study exclusions included: preterm birth (≤37 0/7 weeks' gestation), non-vertex-presentation, cases of a fetus having known anomalies, premature rupture of membranes for more than 8 hours without labor onset, and cases of cesarean birth for the primary indication of non-reassuring fetal heart rate. For this secondary analysis, additional inclusion criteria were oxytocin augmentation and use of an intrauterine pressure catheter (routinely placed in this care setting for titration of oxytocin) (Figure 1). No data on maternal gender identity were available in medical records reviewed for the parent study.

Data Collection. Data for the parent study were abstracted from medical records using REDCap data collection software (NIH/NCRR Colorado CTSI Grant UL1TR001082) (Harris et al., 2009). BMI was calculated using the height and weight at hospital admission for labor. Like other investigators of maternal obesity's influence on intrapartum processes, parent study researchers used BMI at labor admission rather than pre-pregnancy BMI in their analyses, with the rationale that it more accurately reflects the maternal physiologic state during labor (Carlson et al., 2017b; Kominiarek et al., 2011). Obesity was classified using the World Health Organization BMI criteria: obese I

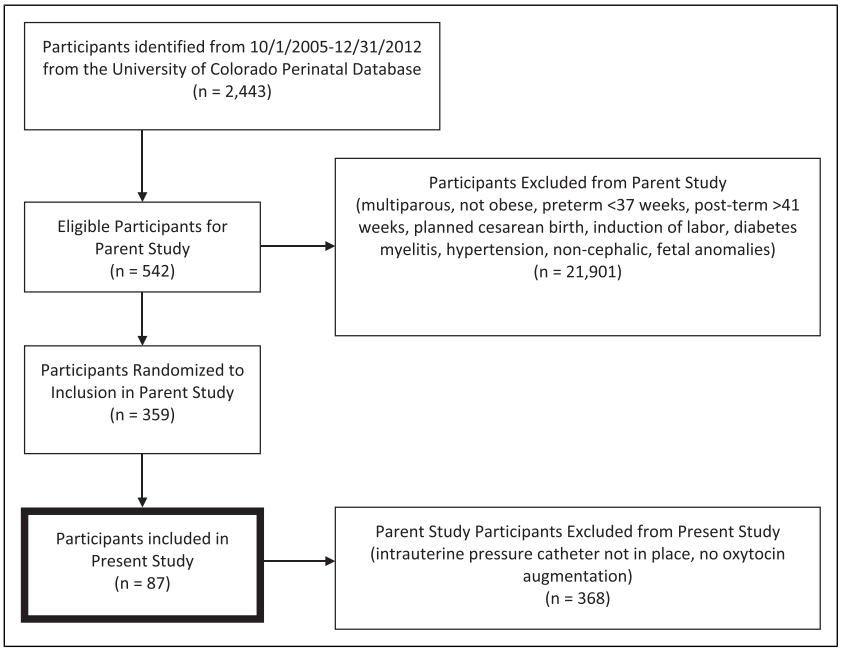

Figure 1. Inclusion/exclusion protocol for parent study and present study.

(30–34 kg/m^2), obese II (35–39 kg/m^2), and obese III (≥40 kg/m^2) (World Health Organization, 2000).

Detailed information about each patients' labor course was collected, including labor duration and the dose and duration of oxytocin augmentation. In addition, data from each cervical exam were collected with time, dilation, station, and effacement (routinely performed every 2 hours during active labor in this care setting). The presence of labor dystocia was determined for each hour of labor using the Zhang et al. (2010) partograph to identify periods of time in which the duration spent without cervical change exceeded the 95th percentile for that integer cervical dilation among low-risk nulliparous people who went on to have a vaginal birth. Each hour was designated as pre-active labor (prior to 4 cm of cervical dilation), active labor with normal progression (within the 95th percentile for that integer cervical dilation), active labor with dystocia (beyond the 95th percentile for that integer cervical dilation), or second stage of labor. Traverse times were calculated as the number of hours an individual remained at a single cervical dilation before making change. The traverse time was divided by the number of centimeters changed between cervical exams to approximate the rate of cervical dilation for each hour of labor.

For each hour of oxytocin augmentation, the titration at the end of the hour (mU/min) was recorded along with the total amount of oxytocin received over the course of the hour (mU/hr). These values were used to calculate the cumulative amount of oxytocin received over the course of labor (mU), the total time of exposure to oxytocin augmentation during labor (min), the mean and maximum oxytocin titrations (mU/min), and the mean and maximum hourly oxytocin doses (mU/hr). MVU were calculated using information from the intrauterine pressure catheter monitoring strip, as noted in the patients' chart by their nurse, by calculating the sum of the change in uterine pressure for each contraction in the last 10 minutes of each hour. Hourly MVU were used to calculate the mean and maximum MVU over the course of labor, and to identify whether a participant reached the 200 MVU threshold during their labor course.

A Priori Power Analysis and Sample Size Justification. Sample size was justified with a priori power analysis using the mean difference in MVUs between nulliparous women with versus without a cesarean birth during active phase labor from a study by Frey et al. (2018; $N = 368$). In that study, the mean uterine activity was 133.6 ± 46.4 MVU ($N = 43$) in women with active phase cesarean birth compared to 187.1 ± 57.2 MVU ($N = 25$) in women who reached complete dilation ($p < .01$). We calculated the effect size (Cohen's d) in this study to be 1.027 standard deviations. Assuming a two-sided $\alpha = 0.05$ and power = 0.8, a sample size of 32 (16 with cesarean birth and 16 with vaginal birth) was estimated to allow for detection of an effect size of 1.027 (G*power, version 3.1). As the actual sample included 27 women with cesarean birth and 60 with vaginal birth, we estimated this study could detect a minimum effect size of 0.78 standard deviations, corresponding to a detectable between-group difference of 40.62 MVU.

Statistical Analyses

Group comparisons of demographic variables, labor characteristics, birth outcomes, and MVU levels in participants with class

1 versus class 2 or 3 obesity were performed using independent t-tests (continuous data), chi-square (categorical data), and Fisher's exact (categorical data with counts less than 5), as appropriate. We also compared labor characteristics, birth outcomes, and MVU levels in participants with vaginal versus cesarean birth. Data were analyzed using IBM SPSS Statistics (Version 28).

For the two primary dependent variables of these analyses (hourly MVU and hourly cervical dilation), we used non-adjusted linear regression to evaluate for associations with other study variables based on associations in the current literature (Carlson et al., 2017b; Chin et al., 2012; Nuthalapaty et al., 2004) (Supplemental Tables 1 and 2). Covariates that were significant predictors of hourly MVU or hourly rate of cervical dilation at the 0.15 significance level in their crude/non-adjusted models were included in the adjusted models. Maternal BMI class was included as a covariate in all adjusted analyses, regardless of significance in unadjusted analyses. Continuous variables were broken into categories to be more applicable for clinicians (maternal BMI was categorized by obesity class and neonatal birthweight was categorized as large-for-gestational-age ≥4000 g or normal-for-gestational age) (Supplemental Tables 3 and 4).

Linear Mixed Modelling. Linear mixed modeling (also known as multilevel linear modeling or hierarchical linear modeling) was selected to evaluate longitudinal data in this study (MVU, oxytocin dose, and rate of cervical dilation). Linear mixed modeling is robust to missing data and incomplete datasets, allowing us to model labor characteristics using what was available in the parent dataset, despite having limited data in some individuals and during different time frames (Cnaan et al., 1997; Field, 2013).

First, we modeled the effects of hourly oxytocin dose (independent variable) on hourly MVU (dependent variable) while accounting for co-variates that we theorized might also affect MVU (maternal BMI, neonatal birthweight, labor stage, and duration of augmentation). Next, we built models to evaluate the influence of hourly MVU (independent variable) on the rate of cervical dilation (dependent variable). For this second set of models, we included additional covariates we theorized would affect the rate of cervical dilation (hours prior to birth and labor stage). The intraclass correlation coefficients were significant for the between-subjects interaction in both models, justifying the use of linear mixed models over simple flat models for these data (Field, 2013).

All multilevel models were constructed with two levels. Level 1 consisted of variables measured longitudinally during labor to contextualize hourly MVU measurements including the hourly oxytocin dose, duration of augmentation, the labor stage (latent, active, or second stage), and the hourly rate of cervical dilation. Level 2 consists of variables describing participants and their overall labor/birth outcomes (e.g., maternal BMI, neonatal birthweight, and cervical dilation at oxytocin initiation) (Supplemental Figures 1 and 2).

Adjusted linear mixed models with random effects for hourly oxytocin dose and time, all the significant co-variates, random slopes and intercepts were fit on hourly MVU and on hourly cervical progression, and the F-statistic was reported as the key parameter to demonstrate the strength of relationship between variables. Then, using the significance (p-value) of each variable and interaction in the model, backward selection was used, iteratively removing the interaction terms and then main terms with the highest p-value until all terms were significant at an alpha-level of $p \leq .01$. A strict alpha of $p \leq .01$ was selected to control for type I error rate inflation due to multiple analyses based on the Bonferroni correction.

Results

Sample Characteristics

Eighty-seven participants were included in the analysis. Participants had an average of 6.21 MVU data points (SD = 3.20, Range 1-18) for a total of 540 data points included in the final analysis. Demographics of the sample are summarized in Table 1. The mean BMI at the time of admission in labor was 35.54 kg/m^2 (SD = 4.28); 52.8% of participants had class 1 obesity, 31% had class 2 obesity, and 16.1% had class 3 obesity. The racial/ethnic makeup of the sample oversampled Black participants compared to the racial/ethnic makeup of childbearing people in Colorado. Midwives provided care for a large percentage of participants compared to the national average.

Labor and birth outcomes in the sample are summarized in Table 2. Twenty-seven (31%) participants had cesarean birth, primarily performed for arrest of dilation (labor dystocia, 74.1%) and arrest of descent (25.9%). Six participants (22.2%) also had a secondary diagnosis of non-reassuring fetal heart tones. Most participants in the sample used epidural or spinal anesthesia (n = 83, 95.4%) and most had anesthesia placed prior to 6 cm (n = 65, 74.7%). No fetal or maternal morbidities occurred in participants included in this analysis; no neonates had Apgar scores <7 at five minutes, and there were two NICU admissions in the first 48 hours (both for observation only).

Rates of Oxytocin Augmentation and Related Factors

15 participants (10.3%) were augmented at 1–3 cm of cervical dilation, 50 (57.5%) were augmented at 4–6 cm, 20 (23.0%) at 7–9 cm, and two (2.3%) at 10 cm. Most participants in the sample had oxytocin augmentation initiated during the active phase of labor, although 15.3% had oxytocin initiated during pre-active labor. When their labors were mapped atop the Zhang partograph, 45 participants (52.6%) had oxytocin augmentation initiated when their labor progress was actually proceeding normally (Zhang et al., 2010).

Differences by Maternal Body Mass Index

In this sample, participants with class 2 or 3 obesity were younger than those with class 1 obesity (Table 1). Labor and birth outcomes, including cesarean birth, oxytocin

Table 1. Demographics.

Demographics	Total	Obese I (BMI 30-34.99)	Obese II or III (BMI ≥35)	
	N (%) or mean ± SD	*N* (%) or mean ± SD	*N* (%) or mean ± SD	*p*-value[a]
Sample size	87	46 (52.8%)	41 (47.1%)	
Age (years)	24.41 ± 4.84	25.74 ± 5.36	22.93 ± 3.70	.005*
18–29	74 (85.1%)			
30–40	13 (14.9%)			
Race/Ethnicity				
Non-Hispanic white	31 (35.6%)	11 (23.9%)	20 (48.8%)	.09
Non- Hispanic African American	14 (16.1%)	10 (21.7%)	4 (9.8%)	
Hispanic	35 (40.2%)	21 (45.7%)	14 (34.1%)	
Other	7 (8.0%)	4 (8.7%)	3 (7.3%)	
Initial provider type				
Certified nurse Midwife	31 (35.6%)	14 (30.4%)	17 (41.5%)	.20
Physician	56 (64.4%)	32 (69.6%)	24 (58.5%)	
Gestational age at birth	39.70 ± 1.00	39.93 ± 0.84	39.56 ± 1.12	.09

Note. *$p < .05$.
[a]*p*-value for difference by birth route using χ^2 (categorical), Fisher's exact (categorical with counts <5) or independent sample t-test (continuous).

dosing, uterine activity, and rate of cervical dilation were not associated with obesity class (Tables 2 and 3 and Supplemental Table 5).

Multilevel Model #1: Hourly Oxytocin Dose and Uterine Activity. Continuous variables were normally distributed without significant skew or kurtosis. In the final linear mixed model of the relationship between hourly oxytocin dose and hourly MVU (Table 4), hourly oxytocin dose had a significant association with hourly MVU ($p < .001$). Admission to the hospital at earlier cervical dilations was associated with lower hourly MVU, an indication of lower uterine activity early in labor ($p = .009$). None of the other co-variates evaluated (obesity class, birth route, oxytocin augmentation restart, large for gestational age neonate) contributed to the relationship between hourly MVU and hourly oxytocin dose (p-values >.013) (Table 4 & Supplemental Tables 1 and 3).

Multilevel Model #2: Uterine Activity and Labor Progression. In the final linear mixed model of the relationship between hourly MVU and hourly cervical dilation, hourly rate of cervical dilation was not predicted by hourly MVU. However, several covariates considered for this model did significantly predict hourly cervical dilation. These included stage of labor and presence of labor dystocia (exceeding the 95th percentile of integer cervical dilation per the Zhang partograph) (Table 5 and Supplemental Tables 2 and 4). However, the average rate of cervical dilation was not associated with BMI, achievement of 200 MVU during labor, or the mean and maximum MVU (p-values >.05) (Table 5 and Supplemental Table 5).

Discussion

Like other studies, we found that nearly half of laboring people with obesity reached or exceeded the MVU ≥200 threshold by the end of active labor (Chin et al., 2012; Hautakangas et al., 2022; Nuthalapaty et al., 2004). In this sample, 45.6% of participants with a vaginal birth had a mean MVU ≥200 in the last 2 hours of active labor, with no differences across obesity classes. Similarly, in a study of 5410 women with intrauterine pressure catheters during labor, Chin et al. reported that 47.9% of women with a vaginal birth had a mean MVU ≥200 in the last 2 hours of active labor and that there was no association between MVU and BMI (Chin et al., 2012).

Building on previous studies, we were also able to analyze MVU data from earlier in labor. This is clinically important, as maternal obesity is known to cause significant slowing of cervical dilation in early to mid-labor (Kominiarek et al., 2011), yet it has not been known how well MVUs predict labor progress at this stage in people with obesity. Interestingly, we found that very few of the obese nulliparas this sample reached the 200 MVU threshold in early to mid-labor (prior to the final 2 hours of active labor). In fact, only 13% of participants who went on to have a vaginal birth reached 200 MVU in early active labor, and almost a fifth of the sample (20.7%) had a vaginal birth without ever reaching 200 MVU. Thus, despite being used nationally to define labor arrest and as an indicator for cesarean birth, MVU were not related to labor progression nor to birth route in this sample of obese nulliparas.

We also found that although oxytocin augmentation was positively associated with uterine contractility in this group, the effect was small. As mentioned previously, the large majority of nulliparas in this sample never reached 200 MVU

Table 2. Labor and Birth Outcomes.

Labor/Birth Outcomes	Total	Obesity Class 1 (BMI 30-34.99)	Obesity Class 2 or 3 (BMI ≥ 35)	
	N (%) or mean ± SD	*N* (%) or mean ± SD	*N* (%) or mean ± SD	*p*-value[a]
Sample size	87	46 (52.8%)	41 (47.1%)	
Birth route				
Cesarean	27 (31.0%)	16 (34.8%)	11 (26.8%)	.73
Vaginal spontaneous	54 (62.1%)	27 (58.7%)	27 (65.9%)	
Assisted vaginal	6 (6.9%)	3 (6.5%)	3 (7.3%)	
Rupture of membranes				
SROM prior to admission	24 (27.6%)	12 (26.1%)	11 (26.8%)	.44
SROM during admission	19 (21.8%)	13 (29.3%)	7 (17.1%)	
AROM	44 (50.6%)	21 (45.7%)	23 (56.1%)	
Postpartum hemorrhage (blood loss ≥1000 mL for cesarean, ≥500 mL for vaginal birth)	18 (20.7%)	9 (19.6%)	9 (22.0%)	.78
Estimated Blood Loss (ml)	508.05 ± 316.49	541.30 ± 363.06	470.73 ± 253.72	.30
Maternal Fever	23 (26.4%)	9 (19.6%)	14 (34.1%)	.12
Fetal position at birth				
Occiput anterior	57 (65.5%)	29 (76.3%)	28 (80.0%)	.64
Occiput posterior	12 (13.8%)	6 (15.8%)	6 (17.1%)	
Occiput transverse	4 (4.6%)	3 (7.9%)	1 (1.2%)	
Manual Rotation	6 (6.9%)	4 (10.5%)	2 (5.6%)	.43
Used maternal position changes to turn fetus	3 (3.4%)	2 (4.3%)	1 (2.4%)	.63
Epidural or spinal	83 (95.4%)	45 (97.8%)	38 (92.7%)	.25
Epidural/Spinal before 6 cm	65 (74.7%)	31 (67.4%)	34 (82.9%)	.09
IV Pain meds	24 (27.6%)	13 (28.3%)	11 (26.8%)	.88
Neonatal birthweight (g)	3378.69 ± 432.31	3378.29 ± 443.89	3379.12 ± 424.73	.99
<4000g	81 (93.1%)	42 (93.3%)	39 (95.1%)	.72
>4000g	5 (5.7%)	3 (6.7%)	2 (4.9%)	
Apgar <7 @1min	19 (21.8%)	9 (19.6%)	10 (24.4%)	.59
Apgar <7 @5mins	0 (0%)	0 (0%)	0 (0%)	
NICU admission in first 48 hrs	2 (2.3%)	2 (4.3%)	0 (0%)	.18
Significant maternal complications	0 (0%)	0 (0%)	0 (0%)	
Length of first stage of labor (min)	684.82 ± 307.08	638.33 ± 286.28	731.30 ± 324.23	.22
Length of second stage labor (min)[a]	80.69 ± 57.71	76.17 ± 55.20	84.57 ± 63.90	.81

Note. SROM = spontaneous rupture of membranes; AROM = artificial rupture of membranes; MVU = Montevideo units; IV = intravenous; NICU = Neonatal intensive care unit.
[a] *p*-value for difference by birth route using χ^2 (categorical), Fischer exact (categorical with counts <5), or independent sample t-test (continuous); **p-value <.01.

Table 3. Differences in MVU by Birth Route.

	Vaginal Birth mean ± SD	Cesarean Birth mean ± SD	$M_{difference}$ [95% CI], t-statistic	*p*-value
Mean MVU early active labor†	165.86 ± 63.63	151.87 ± 45.00	−14.00 [−27.17, −0.82], −2.03	.04*
Mean MVU 2 hours before 2nd stage or cesarean decision	185.15 ± 55.90	154.77 ± 42.12	−30.39 [−49.10, −11.67], −3.21	.002*
Mean MVU	176.30 ± 41.61	166.01 ± 35.86	10.23 [−8.17, 28.63], 1.11	.27
Maximum MVU	228.53 ± 73.63	219.44 ± 63.21	9.09 [−23.44, 41.62], 0.55	.58
Maximum MVU ≥200	42 (70%)	19 (70.4%)	χ^2 = 0.001	.97

Note. *p < .05; †early active labor is defined as > 2 hours prior to complete dilation or the cesarean decision.

Table 4. Multilevel Model #1: Hourly Oxytocin Dose Predicting Hourly MVU.

Variables	F-Statistic	*p*-value[a]	Estimate [95% CI]
Maternal obesity class (Class 1 vs. class 2 or 3)	0.96	.33	8.46 [−8.77, 25.69]
Hourly oxytocin dose (mU)	17.94	<.001*	0.06 [0.03, 0.08]
Duration of augmentation (hours)	0.002	.97	−0.03 [−1.71, 1.64]
Cervical dilation at admission	74.40	.009*	−10.19 [−17.79, −2.59]

Note. *$p < .013$ (with Bonferroni correction accounting for 4 analyses)
[a] *p*-value for difference by birth route using χ^2 (categorical) or independent sample t-test (continuous). The intraclass correlation coefficient (ICC) for the between subjects' interaction was substantial enough to include it in the model (*ICC* = 0.32, $p < .001$) and to justify use of a linear mixed model. The ICC for the interaction over time was very small despite being statistically significant, so it was not included in the final model (*ICC* = 0.009, $p < .001$).

Table 5. Multilevel Model #2: Uterine Activity for Predicting Hourly Average Cervical Dilation.

Variable			
−2 Restricted Log Likelihood	1032.28		
Forced factors	F-statistic	*p*-value	Estimate [95% CI]
Hourly MVU	0.46	.50	<.01
Hourly oxytocin dose (mU)	0.15	.70	<.01
Covariates			
Labor partograph Designation (pre-active, normal active labor, dystocia)	4.59	.01	
Pre-active versus normal active			1.56 [0.41, 2.71]
Dystocia versus normal active			0.35 [0.01, 0.69]
Time (hours prior to birth)	19.92	<.001*	0.10 [0.06, 0.14]
Interaction terms			
Labor partograph Designation with time (hours prior to birth)	6.59	.002*	
Pre-active versus normal active			<.01
Dystocia versus normal active			<.01

Note. * < .008 (with Bonferroni correction accounting for 6 analyses); The intraclass correlation coefficient was sufficient to include the random intercept for the between subjects interaction and to justify use of LMM to predict the hourly rate of cervical dilation (*ICC* = 0.351, $p < .001$).

in early-to mid-labor, and this was despite the fact that everyone in this study received oxytocin augmentation. This finding has important implications for clinical practice, as oxytocin augmentation is used by intrapartum providers to increase MVUs, with the goal of reaching a threshold of 200 MVU when labor progression is expected to take place (or cesarean birth is indicated).

Also, like other studies, we saw evidence that maternal obesity at the time of labor was associated with a longer labor course (Kominiarek et al., 2011; Nuthalapaty et al., 2004). In their analysis of 57,462 nulliparous labors, Kominiarek et al. (2011) reported a dose–response relationship between BMI and the rate of labor progression for each integer centimeter dilation. Those authors found that nulliparas with BMI >40 labored for 1.2 hours longer than nulliparas without obesity at the median, but at the 95th percentile, their labors were 7.2 hours longer (Kominiarek et al., 2011). In our sample of nulliparas with obesity and augmented labor, the median rate of cervical dilation was close to the 95th percentile for nulliparas with BMI 30-40 in the Kominiarek et al. (2011) study. Not surprisingly, this rate of cervical dilation significantly exceeded the 95th percentile rate described by Zhang et al. (2010) in that group's descriptions of labor duration in mixed-BMI groups of laboring people, thus supporting the need for clinicians to gauge labor progression by BMI-individualized, rather than mixed-BMI labor duration statistics.

Given our findings that the risk of cesarean birth in this group was independent of MVU, we suggest alternative measures that incorporate both oxytocin dose and uterine activity may more accurately characterize uterine activity in the context of augmentation and be more useful for treatment algorithms (Frey et al., 2014; Kissler, 2021; Kissler et al., 2020; Kissler & Hurt, 2022). In addition, uterine electromyography may detect nuances in uterine contractility that may differentiate the underlying cause of labor dystocia and predict how an individual will respond to oxytocin augmentation (Kissler et al., 2020).

Overall, our study supports adjustments of national guidelines to no longer rely upon MVU measurements to diagnose labor arrest in laboring nulliparas with obesity. Particularly in early-to mid-labor, MVU measurements do not appear to predict mode of birth and are only minimally responsive to oxytocin augmentation in this group of people. Our findings support the need for innovation in measurement

of uterine activity to more accurately diagnose labor dystocia and its underlying pathophysiology in people with obesity (e.g., uterine under stimulation vs. poor uterine responsiveness to oxytocin augmentation vs. fetal malposition). Precision in labor dystocia diagnosis may lead to the development of targeted and more effective care options.

Limitations

As a secondary analysis of a prospective cohort study in which data were collected from the electronic medical record, this analysis is limited from drawing causal inferences. In addition, this study is potentially limited by the quality of contents of the medical record. Although care was taken in the parent study to prevent errors in data abstraction from the medical records, that study and our own are still subject to charting errors made by the original care teams. Findings from this study may not be generalizable to other populations of laboring people. As indicated by the low cesarean birth rate observed in the parent study (10%) and the lower-than-expected cesarean rate in this group of laboring people who had increased risk for cesarean due to obesity, intrapartum care provided at the medical center of this study may differ significantly from care practices in other settings, especially in rural and private hospitals (Carlson et al., 2017a). In addition, clinician behaviors confound the dosing of oxytocin. While the dosing is typically prescribed algorithmically based on titrating to a certain uterine activity and cervical dilation, titration can also be affected by patient volumes, nurse staffing, fetal response, patient preference, and clinician preference (Lundsberg et al., 2017; Maeder et al., 2020). This may, in particular, vary between care settings and limit generalizability of our findings. A larger sample size would provide more power for detecting smaller differences and improve generalizability. Finally, data in this analysis were collected between 2005 and 2012, thus it may not reflect newer care guidelines or practices. We acknowledge that not all pregnant people identify as women. Theoretically, we anticipate that the findings of this study are applicable to pregnant transgender men and gender non-confirming people and encourage researchers to collect data on gender identity in the future for increased precision.

Conclusion

Our findings indicate that in nulliparas with obesity and augmented labor, oxytocin dosing does not strongly predict uterine activity (measured in MVU). In addition, uterine activity alone is not a good indicator of labor progression nor a predictor of birth route. Finally, the threshold of 200 MVU may not clearly indicate whether 'adequate' uterine activity is achieved during augmentation in the setting of maternal obesity. Standard tools used to augment and monitor slow labor progression may not be useful in nulliparas with obesity. Given the high proportion of people affected by obesity who make up the population of birthing people, and specifically those who are Black, Hispanic or Indigenous, optimizing care for those with obesity is imperative to reduce racial health disparities and improve perinatal outcomes for all families.

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Author Contribution

Kissler, K. contributed to conception and design contributed to acquisition, analysis, and interpretation drafted manuscript critically revised manuscript gave final approval agrees to be accountable for all aspects of work ensuring integrity and accuracy Hernandez, T. contributed to conception and design contributed to acquisition, analysis, and interpretation critically revised manuscript gave final approval agrees to be accountable for all aspects of work ensuring integrity and accuracy Carlson, N. contributed to conception and design contributed to acquisition, analysis, and interpretation critically revised manuscript gave final approval agrees to be accountable for all aspects of work ensuring integrity and accuracy.

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Ethics Approval

Colorado Multiple Institutional Review Board (Protocol #20-1746).

Availability of Data and Material

All data and material are available upon request to the corresponding author.

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Supplemental Material

Supplementary material for this article is available online.

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