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# Lung Protective Ventilation during Pregnancy: An Observational Cohort Study

Yasaswi Kislovskiy, MD[1] Alisse Hauspurg, MD[2,3] Chenell Donadee, MD[4] Sara Sakamoto, MD[2,3] Raghavan Murugan, MD, MS, FRCP[4]

[1] Department of Obstetrics and Gynecology, Women's Institute, Allegheny Health Network, Pittsburgh, Pennsylvania
[2] Department of Obstetrics, Gynecology, and Reproductive Sciences, UPMC Magee-Women's Hospital, Pittsburgh, Pennsylvania
[3] Magee-Womens Research Institute, Pittsburgh, Pennsylvania
[4] Department of Critical Care Medicine, University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania

**Address for correspondence** Yasaswi Kislovskiy, MD, 4800 Friendship Avenue, Pittsburgh, PA 15224 (e-mail: dr.kislovskiy@gmail.com).

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## Abstract

**Objectives** We sought to describe characteristics of mechanically ventilated pregnant patients, evaluate utilization of low-tidal-volume ventilation (LTVV) and high-tidal-volume ventilation (HTVV) by trimester, and describe maternal and fetal outcomes by ventilation strategy.

**Study Design** This is a retrospective cohort study of pregnant women with mechanical ventilation for greater than 24 hours between July 2012 and August 2020 at a tertiary care academic medical center. We defined LTVV as average daily tidal volume 8 mL/kg of less of predicted body weight, and HTVV as greater than 8 mL/kg. We examined demographic characteristics, maternal and fetal characteristics, and outcomes by ventilation strategy.

**Results** We identified 52 ventilated pregnant women, 43 had LTVV, and 9 had HTVV. Acute respiratory distress syndrome occurred in 73% ($N = 38$) of patients, and infection was a common indication for ventilation ($N = 33$, 63%). Patients had LTVV more often than HTVV in all trimesters. Obstetric complications occurred frequently, 21% ($N = 11$) experienced preeclampsia or eclampsia, and among 43 patients with available delivery data, 60% delivered preterm ($N = 26$) and 16% had fetal demise ($N = 7$).

**Conclusion** LTVV was utilized more often than HTVV among pregnant women in all trimesters. There was a high prevalence of maternal and fetal morbidity and fetal mortality among our cohort.

**Keywords**
- mechanical ventilation
- obstetric
- low-tidal-volume ventilation
- respiratory illness
- pregnancy

## Key Points

- Our center utilized low tidal more often than high-tidal-volume ventilation during all trimesters of pregnancy.
- Prone positioning can be performed at advanced gestations.
- Infection is a common cause of antepartum ventilation.

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Lung protective low-tidal-volume ventilation (LTVV) has been shown to decrease mortality and morbidity for nonpregnant ventilated patients, especially in those with acute respiratory distress syndrome (ARDS).[1,2] LTVV use is recommended in pregnancy; however, this ventilation strategy has not been formally studied in the pregnant population.[2–4] While ventilation strategies in pregnancy are understudied, ARDS has been shown to occur more frequently in pregnancy, and pregnant women with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection are at increased risk for mechanical ventilation when symptomatic from coronavirus disease 2019 (COVID-19).[5–8]

Despite the increased risk of requiring mechanical ventilation among critically ill pregnant women, changes in respiratory physiology with advancing gestation and concern for fetal acid–base status may impede utilization of LTVV in pregnancy at later gestational ages.[3,9] Strategies such as permissive hypercapnia, higher respiratory rates, limits for plateau pressure, and prone positioning may be limited by the physiologic changes of pregnancy and the determinants of fetal acid–base status.[3,9] For example, use of permissive hypercapnia in pregnancy is challenged by the need for a placental fetal–maternal $CO_2$ gradient that allows for fetal $CO_2$ elimination. Maternal hypercapnia can thus lead to fetal acidemia, which can reduce the ability of oxygen to bind to fetal hemoglobin. In addition to the physiologic concerns that may prevent use of LTVV in pregnancy, data for ventilation in pregnancy has been limited to case series and consensus statements, and the benefit of LTVV has not been clearly demonstrated among pregnant women.[5,9,10] Especially in the context of the ongoing SARS-CoV-2 pandemic, further information is needed to understand mechanical ventilation in pregnancy.

Our study sought to evaluate characteristics of pregnant women who require ventilation, utilization of LTVV in pregnancy by trimester, and the association of LTVV with maternal and fetal outcomes. We hypothesized that LTVV would be utilized despite advancing gestational age, but that use may be lower later in pregnancy and that LTVV would be associated with improved maternal and fetal outcomes for mechanically ventilated pregnant women.

## Methods

We conducted a retrospective cohort study among pregnant women requiring mechanical ventilation at Magee-Women's Hospital, Pittsburgh, PA, comparing those managed with LTVV with those managed with high-tidal-volume ventilation (HTVV). Magee-Women's Hospital is a tertiary care center with approximately 10,000 deliveries a year, and has a 6-bed obstetric intensive care unit (ICU) and 14-bed medical–surgical ICU. In June 2012, our hospital system began a database of ventilated patients including recording daily average tidal volume, for internal quality performance evaluation. With approval from our Institutional Review Board, we used this database to review charts of ventilated patients and identify pregnant women who required mechanical ventilation during all or a portion of their ventilated days between June 2012 and August 2020. Given our main objective of understanding utilization of LTVV at different gestations of pregnancy, we excluded nonpregnant patients including patients who began mechanical ventilation postpartum. Average daily tidal volume is calculated for each patient and recorded as a part of our hospital's quality database of all ventilated patients. Only an average daily tidal volume is kept in the database, and tidal volume per each ventilated day is not kept in the database. These data are calculated and recorded routinely by the respiratory therapy team, and tidal volume calculations are consistent with previously described criteria from the ARDSnet.[2] We stratified patients by average daily ventilation strategy per ARDSnet protocol, defining LTVV as 8 mL/kg or lower of predicted body weight and HTVV as greater than 8 mL/kg of predicted body weight.

After identifying women who required mechanical ventilation during pregnancy, we performed a retrospective chart review. We collected demographic, medical characteristics, medical and obstetric outcomes, and fetal characteristics. Medical outcomes that were possible before use of ventilation, for example, hypertension in pregnancy, were classified as outcomes when diagnosed during or after ventilation episodes. Regarding medical characteristics, substance use was defined as any patient reported or urine drug screen confirmed use of cocaine, methamphetamines, alcohol, or nonprescribed opiates or benzodiazepines. We categorized indications for intubation and for delivery by expert physician review (Y.K., A.H., and R.M.). To better understand the ventilated cohort, we grouped indications for ventilation by common disease process to create the following four categories: infection; airway protection for substance use, epilepsy, or procedures; cardiac and hypertensive disorders; and asthma. To understand implications of transfer after intubation, we included whether or not a patient had been intubated at a different institution and then transferred for ongoing care. We also collected the number of days of mechanical ventilation at the transferring hospital. Transferring hospital tidal volume strategy was not available for review and was not included in our determination of daily average tidal volume or determination of LTVV or HTVV status.

To understand disease severity among included patients, we collected highest $PaCO_2$ and lowest arterial pH obtained for each patient on day 1 of ventilation. We also calculated Sequential Organ Failure Assessment (SOFA) scores from the first 24 hours of admission.[11] While there is no validated tool to assess severity of disease among pregnant women, data suggest that the SOFA score is least affected by the physiologic changes in pregnancy.[12] To understand the utilization of LTVV by gestation, we stratified patients by trimester of pregnancy at the time of intubation. First trimester was defined as less than 14 weeks of gestation, second trimester defined as 14 or more and less than 28 weeks of gestation, and third trimester defined as 28 weeks or more of gestation. To describe the weight distribution of patients within each trimester, we further stratified patients as underweight for body mass index (BMI) less than 18.5, normal weight for BMI

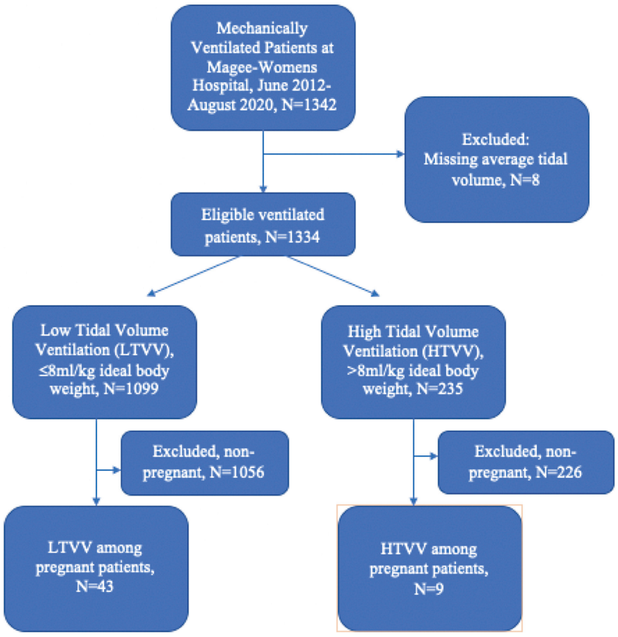


**Fig. 1** Flow chart of mechanically ventilated patients by ventilation strategy and eligibility for inclusion.

18.5 to 24.9, overweight for BMI 25.0 to 29.9, and obese for BMI greater than 30.[13]

Medical and obstetric data were reported by frequency or median with interquartile range (IQR), as applicable. Given our small sample size, we compared groups of categorical variables with Fisher's exact or Kruskal–Wallis tests as appropriate and compared numerical variables by signed rank-sum tests. For characteristics or outcomes with statistically significant difference between LTVV and HTVV, we performed Spearman's rank correlation to understand strength of the association. We used Stata statistical software to perform all statistical tests.

## Results

From June 2012 to August 2020, there were 1,342 patients mechanically ventilated for greater than 24 hours at Magee-Women's Hospital with 5,891 cumulative days of ventilation. ►**Fig. 1** shows exclusion and inclusion criteria and stratification by tidal volume status. We excluded eight patients with 13 ventilated days who did not have an average daily tidal volume recorded. None of the excluded patients was pregnant. Of the remaining 1,334 patients with 5,878 ventilated days, 1,099 patients or 82.3% of patients were managed with LTVV, and 235 patients or 17.6% were managed with HTVV. Of 52 pregnant ventilated patients with 252 ventilated days, there were 43 patients with 186 ventilated days considered to have been managed with LTVV, and there were 9 patients with 66 ventilated days who had been managed with HTVV. Fisher's exact test comparing nonpregnant and pregnant patients by ventilation strategy showed no difference between the groups ($p = 1$).

Demographic characteristics are reported in ►**Table 1**. The median age of the LTVV group was 28 (IQR 24–32), and for the HTVV group, the median age was 32 (IQR 31–33). The median BMI in kg/m$^2$ was 29.5 (IQR 24.5–36) for LTVV and 33.1 (IQR 29.7–33.8) for HTVV patients; 58.1% ($N = 25$) of LTVV patients had a preexisting diagnosis of asthma and 27.9% ($N = 12$) of LTVV patients used tobacco. For the HTVV group, 55.6% ($N = 5$) had been diagnosed with asthma and 77.8% ($N = 7$) used tobacco. We saw substance use among 46.5% ($N = 20$) in the LTVV group and 66.7% ($N = 6$) in the HTVV group. Only 31 patients had hepatitis C test for review and of these women, 43.5% ($N = 10$) had LTVV and 50% ($N = 4$)

**Table 1** Demographic and baseline characteristics

| | Tidal volume $\leq$ 8 mL/kg<br>$N = 43$<br>$N$ (%) | Tidal volume > 8 mL/kg<br>$N = 9$<br>$N$ (%) | $p$-Value |
|---|---|---|---|
| Age (y)[a] | 28 (24–32) | 32 (31–33) | 0.36 |
| Body mass index (kg/m$^2$)[a] | 29.5 (24.5–36) | 33.1 (29.7–33.8) | 0.59 |
| Race | | | |
| White | 34 (79.1) | 9 (100) | 0.33 |
| Black | 9 (20.9) | 0 | |
| Tobacco use | 25 (58.1) | 7 (77.8) | 0.45 |
| Asthma | 12 (27.9) | 5 (55.6) | 0.13 |
| Substance use | 20 (46.5) | 6 (66.7) | 0.47 |
| Chronic hepatitis C[b] | 10 (43.5) | 4 (50) | 1.0 |
| Chronic hypertension | 11 (25.6) | 3 (21.4) | 0.69 |
| Type 1 diabetes | 2 (4.7) | 1 (33.3) | 0.44 |
| Type 2 diabetes | 2 (4.6) | 1 (33.3) | 1.0 |

[a]Median (interquartile range).
[b]Among women for whom hepatitis C test was performed, $N = 31$: low-tidal-volume ventilation $N = 23$, and high-tidal-volume ventilation $N = 8$.

had HTVV. No demographic characteristics were significantly different between the LTVV and HTVV groups.

Medical characteristics are reported in ►Table 2. The median gestational age in weeks at the time of ventilation for LTVV patients was 27 (IQR 19.5–31.2) and 25.4 (IQR 21.4–27) in the HTVV group. Of the 17 patients who were transferred from an outside hospital, all had less than 1 day ventilation at the referring hospital. Arterial blood gases were available for 38 patients and did not differ by ventilation strategy. From data through chart review, SOFA score was able to be calculated for

**Table 2** Medical characteristics

| | Tidal volume ≤ 8 mL/kg<br>*N* = 43<br>*N* (%) | Tidal volume > 8 mL/kg<br>*N* = 9<br>*N* (%) | *p*-Value |
|---|---|---|---|
| Average daily tidal volume, mL/kg[a] | 6.82 (6.37–7.32) | 8.79 (8.37–8.79) | $< 0.05$ |
| Transferred from OSH | 13 (30.2) | 3 (33.3) | 1.0 |
| Average number of days ventilated at OSH[b] | 1 | 1 | 1.0 |
| SOFA score | 8 (6–11) | 5 (4–7) | 0.04 |
| Highest maternal $PaCO_2$[a,c,d] | 43.5 (37–53) | 42 (38–43) | 0.74 |
| Lowest maternal pH[a,d] | 7.29 (7.22–7.34) | 7.3 (7.3–7.31) | 0.89 |
| ARDS | 30 (69.8) | 8 (88.9) | 0.42 |
| Gestational age at the time of diagnosis (wk)[a,b] | 27 (19.5–31.2) | 25.4 (21.4–27) | 0.27 |
| Gestational age at the time of diagnosis by trimester[b] | | | |
| < 14 wks | 4 (9.3) | 2 (22.22) | |
| 14–28 wk | 18 (41.86) | 4 (44.44) | |
| ≥ 28 wk | 21 (48.83) | 3 (33.33) | |
| Indication for mechanical ventilation | | | |
| Infection | 28 (65.1) | 5 (55.6) | |
| Pneumonia | 15 (34.9) | 5 (55.6) | |
| Pyelonephritis | 5 (11.6) | 0 (0) | |
| PICC line–associated sepsis | 2 (4.7) | 0 (0) | |
| Necrotizing fasciitis | 1 (2.3) | 0 (0) | |
| Breast cellulitis sepsis | 1 (2.3) | 0 (0) | |
| Endocarditis | 2 (4.7) | 0 (0) | |
| COVID-19 | 1 (2.3) | 0 (0) | |
| Chorioamnionitis | 1 (2.3) | 0 (0) | |
| Airway protection for substance use, epilepsy, or procedures | 7 (16.3) | 2 (55.6) | |
| Drug overdose | 3 (7) | 1 (11.1) | |
| Status epilepticus | 2 (4.7) | 1 (11.1) | |
| Alcohol use and pseudoseizures | 1 (2.3) | 0 (0) | |
| Transesophageal echocardiogram | 1 (2.3) | 0 (0) | |
| Cardiac and hypertensive disorders | 5 (11.6) | 0 (0) | |
| Eclampsia | 2 (4.7) | 0 (0) | |
| Superimposed preeclampsia with pulmonary edema | 2 (4.7) | 0 (0) | |
| Congestive heart failure | 1 (2.3) | 0 (0) | |
| Asthma | – | – | |
| Asthma exacerbation | 3 (7) | 2 (22.2) | |

Abbreviations: ARDS, acute respiratory distress syndrome; COVID-19, coronavirus disease 2019; OSH, outside hospital; PICC, peripherally inserted central catheter; SOFA, Sequential Organ Failure Assessment.
[a]Median (interquartile range).
[b]Among women transferred from an OSH, *N* = 17.
[c]SOFA scores available for *N* = 50 patients.
[d]Among women with arterial blood gas results for review, *N* = 38: low-tidal-volume ventilation *N* = 38 and high-tidal-volume ventilation *N* = 9.

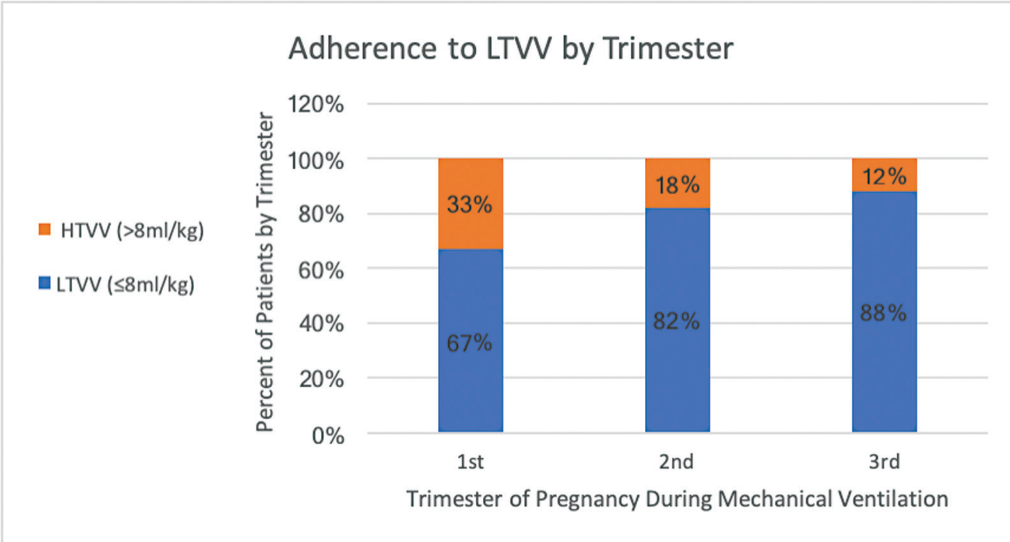


**Fig. 2** Adherence to low-tidal-volume ventilation (LTVV) by trimester of pregnancy. HTVV, high-tidal-volume ventilation. Trimester definitions: first: < 14 weeks of gestation, second: ≥ 14 and < 28 weeks of gestation, and third: ≥ 28 weeks of gestation.

50 patients and median score was 8 (IQR 6–11) and 5 (IQR 4–7) in the LTVV and HTVV groups, respectively. While these groups differed significantly by signed rank-sum test with *p*-value of 0.04, Spearman's rank correlation test for an association between SOFA score and tidal volume strategy was not significant with *p*-value of 0.13.

ARDS occurred in 69.8% ($N = 30$) of LTVV patients and 88.9% ($N = 8$) of HTVV patients. The most common indication for ventilation for both groups was pneumonia, 34.9% ($N = 15$) in the LTVV group and 55.6% ($N = 5$) in the HTVV group. Other infectious indications for ventilation included pyelonephritis, endocarditis, chorioamnionitis, peripherally inserted central catheter line–associated sepsis, necrotizing fasciitis, breast cellulitis, and sepsis. There was one patient with COVID-19-associated ARDS. Other indications for ventilation were drug overdose, alcohol use with pseudoseizures, status epilepticus, asthma exacerbation, eclampsia, superimposed preeclampsia with pulmonary edema, eclampsia, congestive heart failure, and for airway protection during a transesophageal echocardiogram.

The use of LTVV by trimester is shown in ►**Fig. 2**. Among women receiving mechanical ventilation in the first trimester, we identified LTVV use for four patients (66.7%) and HTVV for two patients (33.3%). In the second trimester, we identified LTVV for 18 patients (81.8%) and HTVV for 4 patients (18.2%). In the third trimester, we noted 21 patients (87.5%) had LTVV and 3 (12.5%) had HTVV. Kruskal–Wallis' test showed no difference between LTVV and HTVV by trimester ($p = 0.62$). Fisher's exact test comparing LTVV use in the first trimester ($N = 4$, 9.3%) with LTVV use in the second and third trimesters ($N = 39$, 90.7%) also showed no significant difference ($p = 0.28$). ►**Fig. 3** further stratifies patients by BMI category within each trimester and ventilation strategy. We had no underweight patients. In the first trimester, two patients with HTVV had normal weight, and the categories overweight and obese had two patients each. In the second trimester, LTVV occurred in six normal weight, three overweight, and nine obese patients, and HTVV occurred in one normal weight, one overweight, and two obese patients. In the third trimester, there were six each of normal weight and overweight patients, and there were nine obese patients with LTVV. The three cases of HTVV in the third trimester were obese patients.

In ►**Table 3**, maternal outcomes and fetal characteristics were reported. The median number of ventilated days in the LTVV group was 3 (IQR 1–8) and 3.5 (IQR 2–13) in the HTVV group. There were no maternal deaths in the study population. Eight patients (18.6%) in the LTVV group and one patient (11.1%) in the HTVV group required utilization of prone positioning. Both groups had one patient that required extracorporeal membrane oxygenation (ECMO). Of the patients who underwent prone positioning, two patients were in the third trimester both at 31 weeks, six were in the second trimester with a range of 14.2 to 24 weeks, and one patient in the first trimester at 11 weeks. The patients requiring ECMO were both in the third trimester at 35 and 39.3 weeks' gestation.

On chart review, delivery data were available for 43 patients, and birth weight were available for 36 patients. Of the 39 patients with a documented reason for delivery, 23.3% ($N = 6$) of the LTVV group and 33.3% ($N = 4$) in the HTVV group denoted delivery due to worsening maternal respiratory status. One patient in the LTVV group was delivered due to anticipation of worsening maternal status. The median gestational age at delivery for the LTVV group was 35.6 weeks (IQR 30.5–38) and for HTVV was 32.1 (28.1–35.1). The median birth weight was 2,504 g (IQR 788–3,165) for the LTVV group and 2,268 g (IQR 907–2,875) for the HTVV group. There were seven fetal/neonatal demises, six in the LTVV group, and one in the HTVV group. Of the fetal/neonatal demises, five patients experienced intrauterine fetal demise from 20 weeks' gestational age to 39 weeks due to critical illness including ARDS secondary to pyelonephritis, eclamptic seizure, congestive heart failure, and severe asthma

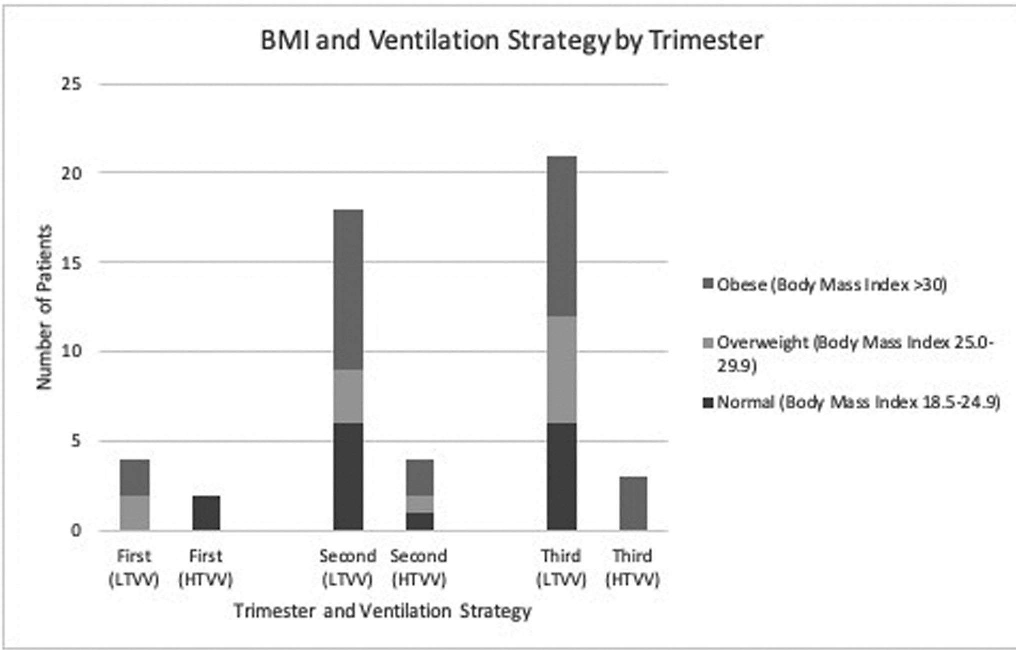


**Fig. 3** Body mass index (BMI) and ventilation strategy by trimester. Trimester definitions: first: < 14 weeks of gestation, second: ≥ 14 and < 28 weeks of gestation, and third: ≥ 28 weeks of gestation.

exacerbation requiring ECMO. One patient had a miscarriage at 12 weeks while undergoing ventilation for status epilepticus. Another patient had spontaneous preterm birth at 20 weeks after preterm premature rupture of membranes and chorioamnionitis causing flash pulmonary edema. Only the patient in status epilepticus was managed with HTVV, and all others were managed with LTVV.

## Discussion

This retrospective cohort demonstrates that LTVV use was similar between nonpregnant and pregnant patients at our institution. There was high use of LTVV even with advancing gestational age and high BMI, and both LTVV and HTVV in pregnancy were associated with similar disease severity measured by arterial pH, $PaCO_2$, and SOFA scores. Among all mechanically ventilated women, there were high rates of comorbid conditions such as chronic hepatitis C virus infection, chronic hypertension, and asthma. We also noted high rates of substance use and tobacco, this may be related to high rates of tobacco use and substance use among pregnant women in our region.[14,15] While our study cannot analyze associations between preexisting medical conditions and need for mechanical ventilation, prior data have shown that tobacco use and substance can increase pulmonary disease severity that may require ventilation.[16] While there were many indications for mechanical ventilation, most were infectious etiologies, and the most common indication for ventilation was pneumonia. Maternal and fetal characteristics and outcomes were similar by ventilation strategy, with high rates of delivery for worsening maternal status among all mechanically ventilated pregnant women. Ventilated women were transferred from an outside hospital quickly, receiving less than 1 day of ventilation at external institutions before transfer.

We cannot report association between outcomes and ventilation strategy from our cohort, yet our study provides detail regarding ventilation strategy, maternal/fetal outcomes, and characteristics.[17,18] Jenkins et al reported characteristics of 51 mechanically ventilated pregnant women from 1990 to 1998 in Nashville and Philadelphia, but did not report tidal volume strategies.[19] Indeed, LTVV was not considered to be standard of care until 2000.[2] Compared with our study, that cohort reflected higher use of ventilation related to hypertensive disorders in pregnancy, $N = 22$ or 43%, and higher maternal mortality, $N = 7$ or 14%.[19] The perinatal mortality rate was similar at $N = 4$ or 11% of the 37 charts with available delivery data. Lapinsky et al did discuss ventilation strategy among their cohort of 29 women identified among obstetric units in Canada, Colombia, Australia, and the United States from 2003 to 2014.[20] Among data that have shown increased risk of ventilation among pregnant women with H1N1, Lapinsky et al's work is unique by reporting tidal volumes used in mechanically ventilated women during the H1N1 era.[6,20] Average tidal volume among the cohort was only reported for the first 2 days of ventilation, 7.7 (SD 1.5) on day 1 of ventilation, and 7.7 (SD 1.9) on day 2 of ventilation. However, average duration of ventilation was 4 days (IQR 2–7) for the cohort and so overall ventilation strategy in the cohort is not clear. Similar to our data, among this cohort, the most common indication for ventilation was infection ($N = 10$ or 34%), and of these patients, five women experienced H1N1 influenza. These authors did not report disease severity and reported Apgar scores and survival status for neonates. This study showed higher rates of maternal mortality than our cohort with three

**Table 3** Maternal outcomes and fetal characteristics

| | Tidal volume ≤ 8 mL/kg<br>*N* = 43<br>*N* (%) | Tidal volume > 8 mL/kg<br>*N* = 9<br>*N* (%) | *p*-Value |
|---|---|---|---|
| Maternal outcomes | | | |
| Number of ventilated days[a] | 3 (1–8) | 3.5 (2–13) | 0.31 |
| Maternal death | 0 | 0 | – |
| Prone positioning use | 8 (18.6%) | 1 (11.1%) | 1.0 |
| Extracorporeal membrane oxygenation use | 1 (2.3%) | 1 (11.1%) | 0.32 |
| Eclampsia/preeclampsia | 10 (23.8%) | 1 (11.1%) | 0.66 |
| Placental abruption | 2 (4.7%) | 0 (0%) | 1.0 |
| Preterm birth[b] | 19 (55.9%) | 7 (77.8%) | 0.28 |
| Fetal characteristics | | | |
| Gestational age at the time of delivery (wk)[a,b] | 35.55 (30.5–38) | 32.1 (28.1–35.1) | 0.35 |
| Gestational age at the time of delivery by week[b] | | | |
| < 24 | 5 (14.7%) | 1 (11.1%) | |
| ≥ 24–33.6 | 7 (20.6%) | 4 (44.4%) | |
| ≥ 34–37.6 | 9 (26.5%) | 2 (22.2%) | |
| ≥ 37 | 13 (38.2%) | 2 (22.2%) | |
| Birth weight (g)[c] | 2,330 (788–3,165) | 2,268 (907–2,875) | 0.29 |
| Fetal/neonatal fetal demise[b] | 6 (18.8%) | 1 (12.5%) | 1.0 |
| Indication for delivery[d] | | | |
| Intrauterine fetal demise | 3 (10%) | 0 (0%) | |
| Term labor | 3 (10%) | 0 (0%) | |
| Elective repeat cesarean | 2 (6.7%) | 0 (0%) | |
| Preterm labor | 2 (6.7%) | 1 (11.1%) | |
| Preterm premature rupture of membranes | 2 (6.7%) | 2 (22.2%) | |
| Nonreassuring antenatal test | | | |
| preterm (< 37 wk) | 4 (13.3%) | 0 (0%) | |
| Term (≥ 37 wk) | 6 (20%) | 2 (22.2%) | |
| Induction of labor for cholestasis of pregnancy | 0 (0%) | 1 (11.1%) | |
| Delivery during mechanical ventilation | 8 (26.7) | 3 (33.3) | |
| Worsening maternal status | 7 (23.3%) | 3 (33.3%) | |
| Anticipation of worsening maternal status | 1 (10%) | 0 (0%) | |

[a]Median (interquartile range).
[b]Among patients with available delivery data, *N* = 43.
[c]Birth weight available for deliveries ≥ 24 weeks, *N* = 36.
[d]When delivery reason available, *N* = 39.

maternal deaths but lower neonatal mortality with only three neonatal deaths. Neither prior study discussed ventilation strategy by gestational age.[19,20] Pregnant women with COVID-19 infection are at higher risk for mechanical ventilation.[7,8] Data from the Gestational Research Assessments for COVID-19 (GRAVID) study used retrospective data from a large cohort of 14,104 patients and demonstrated increased risk of mechanical ventilation among pregnant patients with positive SARS-CoV-2 test (A), but did not report ventilation strategy.

Previous case reports and consensus statements have suggested the utility of LTVV for pregnant women with ARDS.[3–6,9,10,17,18] Prior data have also shown that LTVV with high positive end-expiratory pressure is useful in all ventilated patients, including surgical patients and not just those with acute lung injury of ARDS.[1] Our study includes pregnant women with ARDS and those with surgical indications for mechanical ventilation, and reflects the prior data showing LTVV is utilized among various indications for ventilation.[1] Indications for mechanical ventilation in our study were heterogeneous, revealing high rates of ARDS, infections such as COVID-19 or pneumonia, cardiovascular and hypertensive complications, and intubation for drug overdose. In our cohort, we also demonstrate the use of prone positioning in nine patients, and ECMO used in two patients. This highlights that advanced modalities of ARDS-net protocol and life-saving measures in critically ill women who cannot maintain adequate oxygenation should not be withheld due to pregnancy. Encouragingly, our cohort had no maternal deaths which is improved from prior studies demonstrating maternal mortality when mechanical ventilation is required.[19,20] While our study had seven neonatal/fetal demises, this is consistent with prior data from maternal cohorts with heterogeneous indications for ventilation.[19] Given the lack of prospective data or large cohorts are available for review, it is not clear if LTVV is truly protective and related to the lower rate of maternal mortality over time in the studies assessing ventilation among pregnant women in the United States and other resource-rich settings. LTVV may represent a lung protective strategy among pregnant women, but further research is needed in this group of women at high risk for maternal and fetal morbidities and mortalities.

Our study is limited by its design as a retrospective cohort study performed by chart review. While it is a large cohort of ventilated pregnant patients in the United States compared with the other studies discussed earlier, the cohort size did not allow for analysis of association between ventilation strategy and maternal or fetal outcomes. It is also difficult to ascertain if adverse outcomes are due to critical illness that necessitates mechanical ventilation or due to the ventilation strategy itself. We also determined LTVV or HTVV status by average daily tidal volume ventilation strategy, and data do not provide insight into differences among patients who may have had partial HTVV or partial LTVV during ventilated days. As well, documentation from respiratory therapy regarding average daily tidal volume did not include rational for ventilation strategy, thus our study cannot report allocation reasons for LTVV or HTVV use. Still, our study is a comprehensive review of ventilation strategy among pregnant women that includes measures of disease severity, ventilation over the entire duration of ventilated days, and detailed maternal and fetal characteristics and outcomes.

## Conclusion

Although rare, mechanical ventilation is needed in pregnancy for a variety of etiologies. With the ongoing SARS-CoV-2 pandemic and opioid crises which do not spare pregnant women, understanding the cohort of critically ill pregnant women, and the relationship of pregnancy and mechanical ventilation strategies is vitally important. Our findings show that LTVV is utilized in all stages of pregnancy, even in women with severe respiratory illness or high BMI. The emergence of SARS-CoV-2 highlights the respiratory vulnerability of pregnant women, and our cohort demonstrates the range of indications for ventilation among pregnant women.

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**Conflict of Interest**

None declared.

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