Mechanical Ventilation/ARDS

1. This patient has severe airflow obstruction caused by status asthmaticus and should be managed with ventilation with a prolonged expiratory time. Ventilation in patients with severe airway obstruction may result in breath stacking and auto-positive end-expiratory pressure (auto-PEEP) if sufficient time is not allowed for the preceding breath to be completely emptied. The goal of managing ventilation in patients with severe airway obstruction is to maximize ventilation by allowing adequate time for exhalation and avoid auto-PEEP with resultant increases in end-expiratory pressures, decreased venous return, hypotension, and barotrauma. Ventilation strategies that increase expiratory time include decreasing the tidal volume and respiration rate, increasing inspiratory flow rates, and judicious use of sedation and analgesia. Clinical suspicion of hemodynamic compromise caused by auto-PEEP should be immediately treated by disconnecting the ventilatory circuit at the endotracheal tube to allow trapped intrathoracic air and pressure to escape and venous return to improve. When ventilating patients with severe airflow obstruction, allowing hypercapnia is a permissible strategy. Prolonging the inspiratory time will shorten the time spent in the expiratory cycle and worsen auto-PEEP and ventilation. Similarly, decreasing the rate of inspiratory flow will prolong inspiratory time. Increasing the minute ventilation (hyperventilation) may seem like an appropriate strategy in this patient with respiratory acidosis; however, the physiologic limitation of expiratory flow is the primary determinant of minute ventilation in patients with severe obstruction. Attempts to increase minute ventilation (through increases in respiration rate and/or tidal volume) increase the risk for development of auto-PEEP and hemodynamic compromise.

2. The most appropriate treatment is to increase positive end-expiratory pressure (PEEP) to 10 cm H₂O. This patient has acute respiratory distress syndrome (ARDS) with persistent hypoxemia. Increasing PEEP, FIO₂, and inspiratory to expiratory ratio will all improve oxygenation. PEEP improves oxygenation by recruiting atelectatic alveoli, increasing static compliance, and decreasing shunt. However, at high levels PEEP can lead to barotrauma, low cardiac output, and hypotension. Multiple clinical trials comparing differing levels of PEEP have found no significant differences in survival between higher and lower levels of PEEP; however, there were improvements in some secondary clinical endpoints, especially in the sickest patients with ARDS. Current recommendations are to use an amount of PEEP that achieves an FIO₂ of less than 0.6 and does not cause hypotension. Increasing the respiration rate will increase the minute ventilation and elimination of carbon dioxide, but it will have no effect on oxygenation. Increasing tidal volume may transiently improve oxygenation but will result in a tidal volume higher than 6 mL/kg of ideal body weight (IBW). Survival is improved when patients with ARDS are ventilated with a tidal volume of 6 mL/kg of IBW. Nitric oxide is a pulmonary vasodilator that, when aerosolized, will improve ventilation/perfusion matching and modestly (and transiently) improve oxygenation; however, it has no demonstrated impact on important patient
outcomes such as survival.

3. The most appropriate next step in management is to decrease the tidal volume. The plateau pressure must be decreased to prevent overstretching the lung. The use of low (6 mL/kg predicted weight) rather than standard (12 mL/kg predicted weight) tidal volumes reduces the mortality rate from acute respiratory distress syndrome (ARDS) from 40% to 30%. Elevated plateau pressures were associated with increased mortality in the ARDS Clinical Network trial. In the study, the tidal volume was initially set at 6 mL/kg of ideal body weight (IBW) and was subsequently reduced stepwise by 1 mL/kg IBW if necessary to maintain a plateau pressure less than 30 cm H₂O. The application of this lung-protective ventilator strategy often requires permissive hypercapnia as well as the use of a high FIO₂ to maintain adequate oxygenation in patients with severe ARDS. Permissive hypercapnia is not harmful to the patient; some evidence suggests that mild hypercapnia may decrease the degree of ventilator-induced lung injury. Decreasing the respiration rate or increasing the FIO₂ would not affect the elevated plateau pressure, and increasing positive end-expiratory pressure would increase the plateau pressures further. All of these measures would negate the improved mortality rate associated with the lung-protective ventilatory strategy.

4. The most appropriate tidal volume is 300 mL. The physiologic hallmark of acute respiratory distress syndrome (ARDS) is hypoxemia, which is typically corrected with mechanical ventilation combined with supplemental oxygen and positive end-expiratory pressure (PEEP). Limiting atelectrauma (lung injury that is presumed to arise from repetitive opening and closing of alveoli) and barotrauma may limit the potential for disruption of the alveolar capillary membrane by the ventilator, often referred to as ventilator-associated lung injury. This can be achieved by delivering tidal volumes of limited size, minimizing plateau pressure, optimizing PEEP, and reducing FIO₂ to less than 0.6. Survival is improved when patients with ARDS are ventilated with a tidal volume of 6 mL/kg of ideal body weight (IBW). IBW rather than actual body weight should be used to calculate tidal volume. In patients who are overweight or edematous, using actual body weight will typically result in inappropriately large tidal volumes. A low tidal volume mechanical ventilation strategy is now the standard of care for ARDS. The ARDS Clinical Network trial found a significant reduction in mortality (from 40% to 30%) in the group treated with lower tidal volumes. The tidal volume was set at 6 mL/kg IBW and was subsequently decreased stepwise by 1 mL/kg IBW as necessary to maintain a plateau pressure of no more than 30 cm H₂O. The minimal tidal volume was 4 mL/kg IBW. Ideal body weight is calculated as 50.0 kg (110.2 lb) + 2.3 kg (5.1 lb) for each inch over 60 inches (152.4 cm) in men and 45.5 kg (100.3 lb) + 2.3 kg (5.1 lb) for each inch over 60 inches (152.4 cm) in women. Higher tidal volumes would result in more ventilator-induced lung injury and worse patient outcomes and are therefore not appropriate.