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The use of invasive mechanical ventilation (IMV) via an endotracheal tube, in addition to other interventions such as the use of exogenous surfactant1 and antenatal steroids,2 has contributed to improvement in neonatal survival.3 However, the prolonged use of IMV may predispose infants to the development of various complications, including bronchopulmonary dysplasia.4,5 Avoiding IMV is a goal in clinical care,3 and different modes of non-invasive ventilation (NIV), such as high flow nasal cannula (HFNC),6 nasal continuous positive airway pressure (NCPAP),6 nasal intermittent positive pressure ventilation (NIPPV),7 and its more advantageous form, synchronized nasal intermittent positive pressure ventilation (SNIPPV),8 have been shown to decrease the rate of IMV. For example, though not a feature explored in the current study, the use of SNIPPV has been demonstrated to have several benefits in preterm infants, including decreased work of breathing,9 reduction in incidence of apnea of prematurity,8 shorter duration of ventilation,10 and reduction in death for very low birth weight infants.11 Currently, there are several nasal cannulas (prongs) available for use to deliver HFNC, NCPAP, and NIPPV. These cannulas come in different sizes and lengths, which combined with the ratio of nasal prong to nare diameter, can affect the air pressure delivered to the patient.12 Without proper knowledge of the specific impact of these factors on delivered pressure, clinicians are left guessing what pressure should be set on the ventilation system to deliver adequate support to the patient.12 Airway pressure set on a ventilator and the actual delivered pressure may vary significantly depending on variables including correct sizing, internal diameter of the delivery system, inspiratory time, and cannula length. When oxygen saturation falls as a sign of inadequate support, the clinician may question how much pressure is being delivered to the patient and whether the inspiratory pressure needs to be increased. Being unaware of the actual airway pressure delivered to the patient may lead to erroneous adjustments in the levels of airway support and, in some cases, influence the decision to intubate. Previous bench studies have utilized an artificial nose-throat-lung model to investigate the accuracy of neonatal ventilation approaches. For example, one study measured the delivery of inhaled nitric oxide (NO) in an infant lung model during nasal CPAP, NIV, and HFNC, and found that with HFNC, NO delivery was not accurate, and warned that the set inhaled NO level may not reflect the concentration of NO delivered to the patient.13 Similarly, a separate bench study used a breathing simulator with multiple 3D printed pediatric upper airway sizes to examine the percent of leak using RAM cannula for CPAP delivery. While the amount of leak varied by ventilator settings, approximately 25% of the CPAP was lost due to leaks.14 In another study, Rigotti et al examined pressure transmission with NIPPV using five mechanical ventilators and three nasal interfaces, and found that while the difference between inspiratory and delivered pressure at the airway opening was ±1 cm H2O, there was a significant difference between pressure at the airway and pressure at the glottis.15 The authors concluded that the nasal interface has a more significant impact on delivered pressure than the ventilator type.15 The purpose of this neonatal nasopharyngeal bench study was to measure the delivered pressure from three popular cannulas: Manufacturer A, Fisher & Paykel (Auckland, New Zealand); Manufacturer B, Neotech RAM (Valencia, CA, USA); and Manufacturer C, Hudson RCI (Morrisville, NC, US) using a single ventilator type, across a variety of ventilator settings. Materials and Methods Nasal Model A nasal model was 3D printed and made to fit different size nares. The nasal adaptors were printed in several sizes to accommodate all nasal prongs (Figure 1). The diameter of the nares and the nasal prongs were matched to standardize the fit, such that the prong occupied 85% of nares diameter (Table 1). A pressure transducer (accuracy: ±0.1%, range: ±150 cmH2O) was connected to the nasal model for measurement of pressure at the patient side of the cannula (Figure 2A). A set of IngMar Neolung test lungs (Pittsburgh, PA, USA) was connected to the nares model to simulate patient compliance and resistance (Figure 2B). Table 1 Characteristics of Nasal Cannulas Used in Testing Figure 1 Nasal adaptors with varied nasal diameters to accommodate different sizes of nasal prongs. Figure 2 (A) Schematic for nasal cannula testing (B) Photo of nasal cannula testing setup with 3D printed nares on the lower right side. Prior to the test, each cannula was calibrated by allowing a set gas flow through the cannula, while the internal ventilator pressure was measured for calculation of cannula resistance. Ventilator settings were pressure-controlled ventilation, respiration rate 30 breaths/min and average inspiratory time 375 ms. Ventilator pressures as well as nares pressures were automatically recorded. The smallest cannula from each manufacturer was also tested at inspiratory times 300 ms, 350 ms, 400 ms, 450 ms, and 500 ms. Nasal Cannula Testing Protocol The nasal cannulas tested are summarized in Table 1. To control for variation between ventilators, each cannula was tested using six different Puritan Bennett™ 980 ventilators (Medtronic, Carlsbad, CA). To test the range of ventilator settings and potential setting combinations, ventilator settings were manipulated in a non-uniform manner. This allowed for testing of potentially extreme or uncommon ventilator settings that, although perhaps of limited clinical significance, provided insight into the technical aspects of ventilator performance. This may have led to test conditions that were not reflective of the clinical setting. The testing consisted of a sample of six ventilators tested with eight cases in different settings for each selected cannula size. The eight test cases included: (1) 400 msec inspiration time, 15 cm H2O PEEP, and 10 cm H2O inspiratory pressure; (2) 500 msec inspiration time, 15 cm H2O PEEP, and 25 cm H2O inspiratory pressure; (3) 350 msec inspiration time, 10 cm H2O PEEP, and 10 cm H2O inspiratory pressure; (4) 450 msec inspiration time, 10 cm H2O PEEP, and 30 cm H2O inspiratory pressure; (5) 300 msec inspiration time, 5 cm H2O PEEP, and 10 cm H2O inspiratory pressure; (6) 400 msec inspiration time, 5 cm H2O PEEP, and 20 cm H2O inspiratory pressure; (7) 300 msec inspiration time, 3 cm H2O PEEP, and 12 cm H2O inspiratory pressure; and (8) 300 msec inspiration time, 3 cm H2O PEEP, and 17 cm H2O inspiratory pressure. For each of the eight test cases, 15 breaths were allowed to pass before the final delivered pressure measurements were taken. The resulting sample size for each cannula manufacturer was n = 6 ventilators × 8 test settings × the number of interfaces of different sizes under testing (4, 4, and 3 sizes for Manufacturers A, B, and C, respectively), for a total of n = 192 inspiratory and delivered pressures for Manufacturers A and B, and n = 144 inspiratory and delivered pressures for Manufacturer C. Statistics Analyses were performed using MedCalc Version 11.6.1.0 (MedCalc Software Ltd, Ostend, Belgium), and data were summarized by descriptive statistics for continuous variables or frequencies and percentages for categorical variables. Means and standard deviations were calculated using the number of observations for each cannula over the range of settings and collected readings. Two-sided t-tests were used to compare inspiratory vs delivered pressure for each cannula in each of the 8 test cases, with statistical significance accepted at P0.05), and the cannula from Manufacturer A demonstrated significantly different pressure differences at 300ms and 400 ms ($p < 0.05$). Figure 3 Effect of inspiratory time on the delivered pressure for the smallest cannula size for each manufacturer. Multiple inspiratory times, along with different PEEP and inspiratory pressure ventilator settings were utilized, ranging from 5–15 cm H2O PEEP and 10–25 cm H2O inspiratory pressure. Green bars denote the total inspiratory pressure on the ventilator, for comparison to the delivered pressure. Significant differences between the inspiratory and delivered pressure for each cannula and ventilator setting are denoted as: * p