

# Evaluation of a Nasal Cannula in Noninvasive Ventilation Using a Lung Simulator

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**BACKGROUND:** Nasal noninvasive ventilation (NIV) is a common form of noninvasive respiratory mode used in newborn infants. A next-generation nasal cannula (Neotech RAM cannula) has recently been used to provide nasal NIV. The impact of the Neotech RAM cannula on the delivery of pressure needs to be studied. **METHODS:** In this ex vivo experimental design, a lung simulator (IngMar ASL 5000, version 3.4) was programmed to model a neonate (~1–3 kg of body weight) with normal-to-moderately affected lungs. We used a Covidien PB840 ventilator with NIV software activated to compensate for leaks. Nasal NIV was set at peak airway pressures of 15, 20, and 25 cm H<sub>2</sub>O and PEEP of 5, 6, and 7 cm H<sub>2</sub>O. Three sizes of the Neotech RAM cannula were used (prong outer diameters of 3.0, 3.5, and 4.0 mm). The nose was designed to keep the leak of the nares by the prongs to 30%. We also created a worst case leak (58% leak) by using the largest simulated nostril diameter with the smallest diameter Neotech RAM cannula prong. The outcome measure was the difference in pressures, referred to as leak effect, measured by the lung simulator relative to the set peak airway pressure and PEEP on the ventilator. **RESULTS:** For the interface with 30% leak, leak effects of peak airway pressure during simulated nasal NIV were similar with all Neotech RAM cannula sizes, with 63–75% of peak airway pressure and 70–90% of PEEP being transmitted across the nasal interface. The worst case scenario produced a 92% leak effect in peak airway pressure and PEEP. **CONCLUSIONS:** When used with ≤ 30% leak, the Neotech RAM cannula interface results in clinically acceptable transmission of pressures. With > 50% leak, a clinically negligible amount of pressure is transmitted to the artificial lungs. *Key words: noninvasive ventilation; bronchopulmonary dysplasia; lung distending pressure; nasal cannula; RAM cannula.* [Respir Care 2015;60(4):508–512. © 2015 Daedalus Enterprises]

## Introduction

Noninvasive ventilatory support is the mainstay of respiratory management in preterm infants. Nasal intermittent

positive-pressure ventilation, a form of nasal noninvasive ventilation (NIV), is a common form of noninvasive ventilatory support in very low birthweight infants. The main aims of nasal NIV are to reduce the frequency of apnea, extubation failure, and bronchopulmonary dysplasia.<sup>1–4</sup> By providing a continuous distending pressure and intermittent breaths, nasal NIV devices are supposed to improve tidal volumes ( $V_T$ ), reduce the work of breathing, improve oxygenation, and increase carbon dioxide elimination.<sup>5,6</sup> Nasal NIV is delivered by a variety of devices that generate either a preset flow or a preset pressure to the nares. Flow generators (eg, Infant Flow SiPAP system, CareFusion, San Diego, California) maintain a constant flow through the system and develop pressure as a back pressure in proportion to the set flow and impedance of an infant's respiratory system. In the bi-level mode, SiPAP provides 2 levels of CPAP and is supposed to augment the functional residual capacity.<sup>7</sup> Conventional mechanical

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Neotech supplied cannulas and artificial nose fixtures. Mr Chatburn has disclosed relationships with Neotech and IngMar Medical.

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ventilators are also used in pressure control modes, particularly when an NIV feature is available. This feature allows for compensation of the expected leaks when using NIV interfaces such as CPAP prongs or high-flow nasal cannulas. This diversity of machines is, in part, responsible for considerable inpatient and outpatient variation in the effectiveness of noninvasive respiratory support.<sup>8,9</sup> A next-generation nasal cannula (RAM cannula, Neotech, Valencia, California) has recently been used as an interface to provide noninvasive ventilatory support, such as nasal intermittent positive-pressure ventilation, CPAP, and noninvasive neurally adjusted ventilatory assist.<sup>10</sup> The impact of the Neotech RAM cannula on the delivery of pressure and  $V_T$  needs to be studied to allow clinicians and therapists to use the cannula effectively.

The main purpose of this study was to determine the relation between set and delivered pressures during NIV of a lung simulator using the Neotech RAM cannula.

## Methods

### Study Design

We used an ex vivo experimental design with a lung simulator and plastic fixtures to represent the infant nose (3 sizes).

### Equipment and Settings

An ASL 5000 lung simulator (version 3.4, IngMar Medical, Pittsburgh, Pennsylvania) was programmed to model a neonate (~1–3 kg of body weight) with normal-to-moderately affected lungs<sup>11</sup>: compliance, 1.5 mL/cm H<sub>2</sub>O; resistance, 70 cm H<sub>2</sub>O/L/s; and maximum simulated muscle pressure, zero (passive model).

Data from a previous study<sup>12</sup> were used for choosing ventilator settings: ventilator, PB840 ventilator (Covidien, Mansfield, Massachusetts) with mode set to pressure control continuous mandatory ventilation with noninvasive leak compensation active; peak airway pressure (above atmospheric pressure), 15, 20, and 25 cm H<sub>2</sub>O; PEEP during CPAP mode, 5, 6, and 7 cm H<sub>2</sub>O; breathing frequency, 40 breaths/min; and inspiratory time, 0.5 s. The lung simulator calculated the mean values from 10 breaths in each experimental condition.

There are 3 sizes of the Neotech RAM cannula currently available, with prong outer diameters of 3.0 mm (preemie), 3.5 mm (newborn), and 4.0 mm (infant). Cannula sizes are selected using a template intended to match the prong size to the approximate patient size in terms of nostril diameter. The template is designed so that the cross-sectional area of the Neotech RAM cannula prongs is ~70% of the cross-sectional area of the nostrils (ie, ~70% occlusion).

## QUICK LOOK

### Current knowledge

Noninvasive ventilation via the nasal route is a common form of noninvasive ventilatory support in newborn infants. A number of nasal interfaces have been used for support, including a specially designed nasal cannula.

### What this paper contributes to our knowledge

Using a next-generation cannula interface in a model system, with a properly sized cannula-to-nasal diameter, resulted in transmission of 60–70% of the set peak airway pressure and PEEP. When the cannula size was too small relative to the nasal model diameter, pressure transmission was significantly reduced, resulting in a minimal amount of pressure being applied to the model.

The nose was simulated with a fixture created with a 3-dimensional printer. The fixture was attached to a standard 22–15-mm adapter for connecting to the lung simulator (Fig. 1). The fixture was not intended to reproduce actual anatomic contours but rather simply to provide a convenient and realistic connection between the nasal cannula and lung simulator. Three fixtures were made with nostril diameters of 3.4, 4.0, and 4.6 mm (same as the cannula sizing template and corresponding to the cannula sizes).



Fig. 1. Nasal fixture.

Table 1. Measured Peak Airway Pressure in a Simulated Nose at Different Set Peak Airway Pressures

	Cannula Size (mm)	Nostril Size (mm)	Measured Peak Airway Pressure (cm H <sub>2</sub> O)			Leak Effect (%)		
			15 cm H <sub>2</sub> O Set Peak Airway Pressure	20 cm H <sub>2</sub> O Set Peak Airway Pressure	25 cm H <sub>2</sub> O Set Peak Airway Pressure	15 cm H <sub>2</sub> O Set Peak Airway Pressure	20 cm H <sub>2</sub> O Set Peak Airway Pressure	25 cm H <sub>2</sub> O Set Peak Airway Pressure
Preemie	3.0	3.4	10.0	13.0	15.8	-33	-35	-37
Newborn	3.5	4.0	10.0	13.2	16.0	-33	-34	-36
Infant	4.0	4.6	11.3	14.9	18.3	-25	-26	-27
Worst case	3.0	4.6	1.3	1.7	2.2	-91	-92	-91

All values are averages. SD was virtually zero (< 0.02 cm H<sub>2</sub>O) due to the nature of the simulation.

### Leak Conditions

Four leak conditions were simulated: 3 normal leaks (representing appropriate cannula size selection) and 1 worst case leak (representing inappropriate sizing of the cannula). The normal leaks were created using the 3 sizes of the Neotech RAM cannula with their 3 recommended nares sizes as determined using the sizing template. The worst case leak (~58% leak) was created by using the largest simulated nostril diameter from the sizing template (4.6 mm) with the smallest diameter cannula prong (3.0 mm). This was considered the worst case scenario in the sense that it is the most inappropriate fit possible using the available cannula sizes and the sizing template.

### Outcome Measures

Pressures transmitted from the ventilator to the simulated nose were recorded by the ASL 5000 lung simulator (called mouth pressure by the software). Pressure waveforms were analyzed using the Post-Analysis software of the lung simulator. Peak airway pressures and PEEP values from these waveforms represented the true ventilating pressures as opposed to the set pressures read on the ventilator. The outcome was the difference in peak airway pressure and PEEP, referred to as leak effect, measured by the lung simulator (ie, the delivered true values) relative to the set peak airway pressure and PEEP on the ventilator. This difference was expressed as a percent leak effect relative to the ventilator setting: % leak effect = ((measured pressure - set pressure)/set pressure) × 100%. Thus, negative leak effect values indicate that the measured pressure was less than the set pressure.

We also measured the mean airway pressure and  $V_T$  generated in the artificial lungs. Flow and volumes are measured internally in the ASL 5000 unit, and no external sensors are used for this purpose.

### Statistical Analysis

We present descriptive statistics as mean values only. Because these mean values were calculated from several

nearly identical breaths on a passive lung model, the SD was virtually zero (ie, < 0.02 cm H<sub>2</sub>O, well below the measurement error of a ventilator pressure display).

### Results

For all experimental conditions, the actual pressures generated in the simulated nose were less than the pressures set on the ventilator (hence, leak effect values are negative), as shown in Table 1. Table 1 indicates that leak effects of peak airway pressure during simulated nasal NIV were similar across sizes, but were slightly higher for the preemie cannula and lowest (~25%) for the infant cannula. The worst case scenario (preemie cannula with infant nares) produced a 92% leak effect in peak airway pressure.

This order of magnitude for leak effect was the same for PEEP leak effect (Table 2), although the absolute values were different (range of 10–92%). We are unable to explain the variation in the measured PEEP while using the newborn cannula. The other cannula sizes showed a trend of increasing percentage leak effect with increasing PEEP.

Mean airway pressure increased linearly with the increase in set peak pressure as shown in Table 3. We could not record the mean airway pressure for the worst case scenario.

The  $V_T$  also increased with the increase in peak pressures and ranged from 13 to 29.6 mL (Table 4).  $V_T$  in the worst case was very small and ranged from 1.9 to 3.1 mL.

### Discussion

Clinicians need to recognize the effectiveness and limitations of newer devices and interfaces, such as the Neotech RAM cannula, particularly when used in novel applications. In this simulation-based experiment, we evaluated the use of the Neotech RAM cannula in nasal NIV. Our results show that transmission of pressure across the nasal interface is dependent on the leak at the interface, with good pressure transmission when the nasal cannula is prop-

Table 2. Measured PEEP in a Simulated Nose at Different PEEP Settings

	Cannula Size (mm)	Nostril Size (mm)	Measured PEEP (cm H <sub>2</sub> O)			Leak Effect (%)		
			5 cm H <sub>2</sub> O Set PEEP	6 cm H <sub>2</sub> O Set PEEP	7 cm H <sub>2</sub> O Set PEEP	5 cm H <sub>2</sub> O Set PEEP	6 cm H <sub>2</sub> O Set PEEP	7 cm H <sub>2</sub> O Set PEEP
Preemie	3.0	3.4	4.1	4.2	4.8	-18	-30	-31
Newborn	3.5	4.0	4.0	5.1	5.8	-20	-15	-17
Infant	4.0	4.6	4.5	5.1	5.7	-10	-15	-19
Worst case	3.0	4.6	0.4	0.6	0.7	-92	-90	-90

All values are averages. SD was virtually zero (< 0.02 cm H<sub>2</sub>O) due to the nature of the simulation.

Table 3. Measured  $\bar{P}_{aw}$  in a Simulated Nose at Different Set Peak Airway Pressures

	Cannula Size (mm)	Nostril Size (mm)	Measured $\bar{P}_{aw}$ (cm H <sub>2</sub> O)		
			15 cm H <sub>2</sub> O Set Peak Airway Pressure	20 cm H <sub>2</sub> O Set Peak Airway Pressure	25 cm H <sub>2</sub> O Set Peak Airway Pressure
Preemie	3.0	3.4	6.4	7.5	8.5
Newborn	3.5	4.0	6.3	7.4	8.5
Infant	4.0	4.6	7.0	8.3	9.6
Worst case	3.0	4.6	≈0	≈0	≈0

All values are averages. SD was virtually zero (< 0.02 cm H<sub>2</sub>O) due to the nature of the simulation.

$\bar{P}_{aw}$  = mean airway pressure

Table 4. Measured V<sub>T</sub> in Simulated Lungs at Different Set Peak Airway Pressures

	Cannula Size (mm)	Nostril Size (mm)	Measured V <sub>T</sub> (mL)		
			15 cm H <sub>2</sub> O Set Peak Airway Pressure	20 cm H <sub>2</sub> O Set Peak Airway Pressure	25 cm H <sub>2</sub> O Set Peak Airway Pressure
Preemie	3.0	3.4	13.0	19.0	25.6
Newborn	3.5	4.0	13.0	19.7	26.0
Infant	4.0	4.6	14.7	22.0	29.6
Worst case	3.0	4.6	1.9	2.6	3.1

All values are averages. standard deviations were virtually zero (< 0.02 ml) due to the nature of the simulation.

V<sub>T</sub> = tidal volume

erly sized using a template, but with very little transmission when sizing is inappropriate.

There was loss of 25–37% of peak pressure across the interface for different settings. We speculate that this degree of inspiratory pressure leak effect may be clinically acceptable in terms of providing ventilatory support to infants represented by our lung model parameters (ie, weighing 1–3 kg with normal lungs or moderate lung dis-

ease). We base this speculation on the fact that V<sub>T</sub> delivered by the actual nasal pressure changes was on the order of 13–29 mL. These volumes would be considered satisfactory to high for most newborn infants. However, in studies on newborn infants, synchronized delivery of nasal intermittent positive-pressure ventilation either did not change or minimally changed V<sub>T</sub> delivery. Reasons for this discrepancy are, for now, unknown.<sup>5,13</sup> Given that this was a passive model and that NIV is virtually always applied to patients who can sustain some degree of inspiratory effort, the level of support given to a real patient using these cannula sizes would be appropriate with minor ventilator adjustments. Measured PEEP levels during simulated nasal NIV were also acceptable.

The data for the worst case scenario (smallest prongs and largest nares diameter) indicate the importance of correct sizing of prongs to the patient’s actual nasal dimensions during NIV using a nasal cannula as the patient-ventilator interface (eg, as opposed to a tight-fitting mask). This implies the need for clear and detailed product information and adequate clinician training. The data from this study also highlight the importance of appropriate sizing template dimensions. We conclude that the sizing template used in the study (which assumes a 70% occlusion based on relative areas of nostril and nasal prong) is appropriate.

Our study has limitations. Lung simulator-based studies represent the best case scenario and do not account for the variability associated with daily use, such as a nasal cannula being loose-fitting or partially out or blocked with secretions. However, lung simulator studies, such as ours, inform us about the physical properties associated with the nasal cannula interface with a high level of accuracy and reliability. The lung simulator simply provided a load with values of resistance and compliance for the respiratory system that are representative of a particular size neonate. The actual values are relatively unimportant because of the high variability of mechanical properties, including highly variable inspiratory/expiratory efforts. The point of using a passive simulation is to highlight the basic physics of the patient-ventilator system under ideal conditions to help understand the clinical implications of a nasal cannula for

NIV. Our results are not intended to guide setting of inspiratory pressure on the ventilator. The relationship between set inspiratory pressure and the pressure/volume delivered to the lungs in an actual clinical situation is dependent on many uncontrollable factors, which is why NIV, in general, and NIV through nasal prongs, in particular, are exercises in rough estimates at best. The leak compensation option (ie, using the noninvasive feature) on the PB840 ventilator is designed to compensate for leaks in the breathing circuit to maintain PEEP and prevent autotriggering during NIV and invasive ventilation. It is possible that not using the leak compensation for this experiment or using a different ventilator that does not offer leak compensation may have yielded different results. Further study of this issue is warranted.

In conclusion, when properly sized to nasal diameter, the Neotech RAM cannula interface results in transmission of 60–70% of the set peak airway pressure and PEEP. When the cannula size is not appropriate, the resulting pressure transmission is drastically reduced, resulting in a clinically negligible amount of pressure being applied to the artificial lungs.

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