



**VAPOTHERM**

**ROLE OF PRESSURE  
IN HIGH FLOW THERAPY**

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This information is provided in response to requests from users to elaborate on the role of pressure in a high flow nasal cannula system. This educational paper provides summary material related to flow and pressure from the respiratory and neonatal literature.

Material contained herein is not designed to provide clinical practice guidelines and is consistent with official instructions for use for Vapotherm, Inc.

### **Indications for Use for Vapotherm® High Flow Devices:**

Vapotherm, Inc. manufactures high flow humidification devices and patient circuits for use in respiratory support for neonatal, pediatric and adult patients. These products are not intended for use as continuous positive airway pressure (CPAP) devices, but rather as high flow systems to deliver conditioned breathing gases. Vapotherm recommends that users always maintain an open system, including applying a cannula that does not occlude more than 50% of the patient's nares.

### **Precision Flow™**

The Precision Flow™ is intended to be used for adding warm moisture to breathing gases from an external source for administration to a neonate/infant, pediatric and adult patient in hospitals, sub-acute institutions, and home settings. It adds heat and moisture to a blended medical air/oxygen mixture and assures the integrity of the precise air/oxygen mixture via an integral oxygen analyzer. The flow rates may be from 1 to 40 liters per minute via nasal cannula.

### **Vapotherm 2000i®**

The Vapotherm 2000i is designed to add moisture to and to warm breathing gases for administration to patients, including neonates/infants, pediatrics, and adults. The flow rates may be from 1 to 40 liters per minute via nasal cannula. Environments for use include home, hospital, and sub-acute institutions.

## **BACKGROUND ON MECHANISMS OF ACTION IN HIGH FLOW THERAPY**

Recent developments in gas conditioning technology introduced by Vapotherm have facilitated the expansion in the use of a nasal cannula. No longer restricted to conventional flow limitations ( $\leq 6$  L/min in adults;  $\leq 2$  L/min in infants), nasal cannulae are now being used for High Flow Therapy (HFT™). HFT™ refers to the use of nasal cannula gas flows that exceed patient inspiratory flow rates such as to: 1) insure that the patient will inspire the intended gas composition without entrainment of room air, and 2) provide for other physiologic impacts including purging of end-expiratory gas from the nasopharynx during expiration and development of mild distending pressure.

In a recent paper by Dysart and colleagues, five potential underlying mechanisms of action for HFT™ are identified<sup>1</sup>:

- 1) Washout of the nasopharyngeal dead space
- 2) Reduction in inspiratory resistance associated with gas flow through the nasopharynx
- 3) Improvement in respiratory mechanical parameters associated with gas temperature and state of humidification
- 4) Reduction in metabolic work associated with gas conditioning
- 5) Provision of mild distending pressure

This paper discusses topics related to the fifth identified mechanism, distending pressure, with respect to nasopharyngeal pressure development and including expected pressure ranges and safety. Specifically, the scope of this paper will define the relationship between pressure in the patient circuit and the nasopharynx, and identify the factors that contribute to inadvertent pressure development.

### **KEY DEFINITIONS**

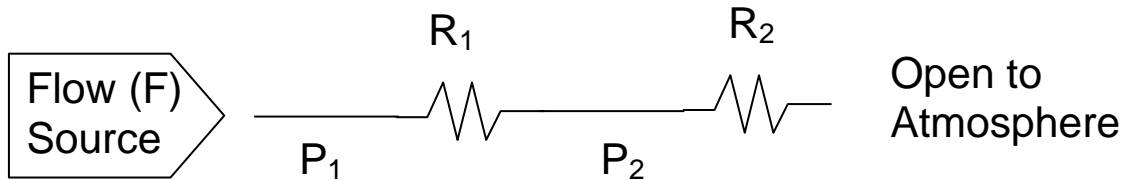
<b>High Flow Therapy (HFT™):</b>	Respiratory gas therapy where the flow from the external gas source exceeds a patient's inspiratory flow rates, eliminating entrainment of room air during inspiration.
<b>Patient Circuit:</b>	Tubing connecting the gas source to the cannula.
<b>Nasopharynx:</b>	The body cavity being purged during HFT™.
<b>Pressure:</b>	The distending force created when a gas stream comes in contact with resistance.
<b>Flow:</b>	The stream or current of respiratory gas through the device and respiratory systems, typically quantified in liters per minute (L/min).
<b>Resistance:</b>	A force that tends to oppose flow, resulting in back pressure.
<b>Resistor:</b>	A specific point or region in the flow path that has been identified as having relatively high resistance, resulting in significant backpressure (i.e. a bottleneck).

### **FLOW AND PRESSURE FUNDAMENTALS**

HFT™ is intended to be an open system, with flow delivered to a patient via nasal cannula, where the cannula prongs do not occlude the nares and where the patient's mouth is not held closed. In this open system, the pressure in each compartment is a function of the resistor(s) that lie in series downstream from that compartment. In this regard, circuit pressures will always be substantially greater than pressure in the nasopharynx\*. To explain why circuit pressures will always be substantially greater than nasopharyngeal pressure, consider Figure 1.

(\*NOTE: the exception to this rule would be in the event of a complete or nearly complete blockage of flow exiting the patient's nasal and oral orifices. The Vapotherm® Precision Flow™ is designed with the ability to recognize an occlusion and alarm, and halt flow until the occlusion has been resolved.)

FIGURE 1. SCHEMATIC OF A HIGH FLOW THERAPY CIRCUIT / PATIENT INTERFACE



*R = resistive element; P = pressure compartment impacted by downstream resistance*

Figure 1 demonstrates that there are two principle resistors and thus two pressure compartments in the circuit / patient interface. Resistor #1 ( $R_1$ ) represents the nasal cannula and therefore pressure compartment #1 ( $P_1$ ) represents the patient circuit. Resistor #2 ( $R_2$ ) represents the components resistive to gas exhausting from the patient's nose (around the cannula) and mouth and therefore pressure compartment #2 ( $P_2$ ) represents pressure generated in the nasopharynx. For each pressure compartment, the established pressure is a result of the total downstream resistance ( $R_T$ ; Equation 1); therefore,  $P_1$  is always a function of both  $R_1$  and  $R_2$ , while  $P_2$  is only ever a function of  $R_2$ . Furthermore, because under normal conditions  $R_1$  is dramatically greater than  $R_2$ , we can expect  $P_1$  to be much greater than  $P_2$ .

EQUATION 1: DEFINITION OF TOTAL RESISTANCE FOR SERIES RESISTORS

$$R_T = R_1 + R_2$$

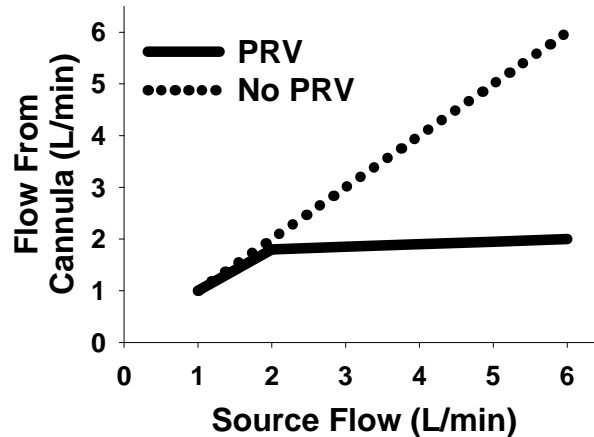
*Where  $R_T$  is total resistance and  $R_1$  and  $R_2$  are individual resistors in series*

### **PRESSURE IN THE DEVICE CIRCUIT**

The aforementioned principles translate to practical application of HFT™ therapy in the following manner. Because a nasal cannula offers such a high resistance to flow, any device intended to drive high flow rates through a cannula (defined in respiratory care terms as  $> 6$  L/min) must be designed to contain and function under these normally high operating patient circuit pressures. Any attempt to relieve circuit pressures via a pressure relief valve to protect device components, would naturally result in a reduction of actual flow through the cannula thus lessening the intended flow (see Figure 2)<sup>2</sup>. However, the

high circuit pressures do not translate to the patient because they are a function of the cannula resistance which is upstream to the nasopharynx.

FIGURE 2. IMPACT OF A PRESSURE RELIEF VALVE IN A HFT™ SYSTEM



*This figure is reproduced from data presented in Lampland et al<sup>2</sup> using a Fisher and Paykel® system with and without a pressure relief valve (PRV) set to 45 cmH<sub>2</sub>O. With the pressure relief valve in place, the system does not permit more than 2 L/min to pass through the cannula regardless of the flow entering the humidifier.*

### **PRESSURE IN THE NASOPHARYNX**

Nasopharyngeal pressure (positive airway pressure) is determined by three principle factors<sup>3</sup>:

- 1) the flow setting,
- 2) the patient's unique anatomical dimensions, and
- 3) the leak out of the nose around the prongs and out of the mouth.

In HFT™, the basic flow setting is meant fundamentally to exceed normal inspiratory flow rates so as to eliminate entrainment of room air. Inspiratory flow rates can be easily calculated for a patient based on actual or predicted values (Equation 2). For example, if an adult patient exhibits textbook values for respiration (tidal volume = 500ml, breathing frequency = 12 br/min, inspiratory time fraction is 0.3), then inspiratory flow rate is approximately 20 L/min. In this case, a HFT™ flow setting of 25 L/min would ensure meeting the definition of HFT™. At these relatively moderate flow rates only moderate nasopharyngeal pressure can be expected, and flow rates can be titrated upward to enhance nasopharyngeal washout effects without generating substantial increases in pharyngeal pressure. However, Vapotherm emphasizes that during HFT™ pressure is not the principle mechanism of action and caregivers should not utilize excessive flows in an attempt to generate substantial distending pressures.

EQUATION 2: CALCULATION OF HFT™ FLOW RATES FOR PATIENT PREDICTED VALUES

$$V_I = (V_T \times f) / F_{ti}$$

*Where  $V_I$  is inspiratory flow in L/min,  $V_T$  is tidal volume in L,  $f$  is breathing frequency in breaths/min and  $F_{ti}$  is fraction of inspiratory time (typically 0.3)*

Anatomical size of the patient at the nares and internally are factors in determining distending pressure<sup>3,4</sup> because anatomy largely defines the resistance to flow passing through and out of the nasopharynx. However, if flow ranges are determined based on predicted normal inspiratory flow rates, then anatomical features are accounted for as these computations account for a patient's size. The relationship between anatomy and flow resistance is more clinically relevant with infants as opposed to adults, where in some cases just two or three liters per minute of flow may constitute HFT™.

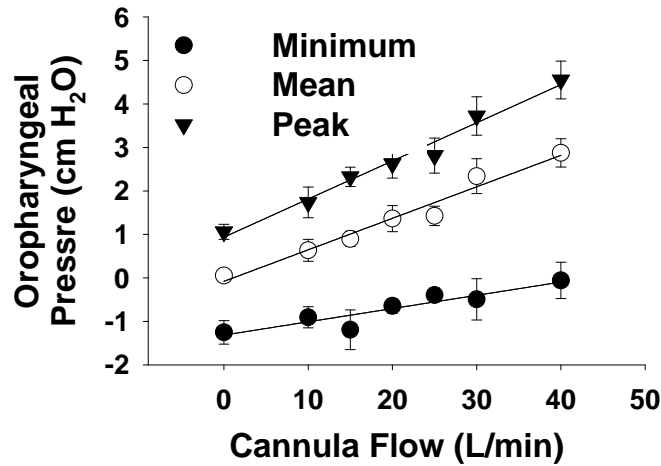
The most critical factor in determining nasopharyngeal pressure development when initiating HFT™ is the relationship between internal diameter of the nares and the size of the nasal cannula used<sup>3,5,6</sup>. Going back to the original report of pressure development with a nasal cannula, esophageal pressure was not recordable when a very small cannula was used, but mild pressure was produced when a larger cannula, relative to the patient size, was used at the same flow rate<sup>5</sup>. In a bench model, Kahn and colleagues demonstrate that nasopharyngeal pressure development is predominantly a function of the leak around the prongs<sup>3</sup>, thus making the selection of which nasal prong size to use an important part of applying the therapy.

Vapotherm recommends selecting nasal prongs that have an outside diameter no more than 50% of the inside diameter of the patient's nares. With this fitting mild distending pressure will develop, which will support the other mechanisms of action; however, there is still adequate room for leak around the prongs. The leak is necessary to allow for a reasonable amount of flush in the nasal cavity to accomplish the actions of dead space washout.

**EXPECTED NASOPHARYNGEAL PRESSURE RANGES**

In the adult patient population, caregivers have not often raised concerns about pressure development. This is presumed to be because the large anatomical size in the adult is not considered conducive to excessive pressure development relative to the airway pressures provided by pressure support therapies. However, Bamford and colleagues presented in abstract form a study demonstrating oropharyngeal pressures in adults<sup>7</sup>. These data are presented in Figure 3.

FIGURE 3: OROPHARYNGEAL PRESSURES IN ADULTS DURING HFT™



*Reproduced from Bamford et al 2004<sup>7</sup>; Data are means ± SEM for minimum, peak and mean oropharyngeal pressures.*

In the neonatal community, a significant body of literature has been amassed to describe the resultant airway pressures during the application of HFT™. Table 1 reports the findings from these studies, which are consistent in agreement that maximum pressures are typically not different from a CPAP setting of 6 cmH<sub>2</sub>O. Note that in a number of these studies, the protocols called for a closed mouth and occluded nares in an effort to establish greater pressures.

## **CONCLUSION**

Pressure in the patient circuit is necessary to drive high flows through a nasal cannula, but this circuit pressure is isolated from the patient's nasopharynx. In individual patients, nasopharyngeal pressure during HFT™ is dependent on factors which include flow rate, patient's size and the relationship between cannula prong size and the internal diameter of the nares. However, pressure generation has been evaluated in a number of recent papers and shown to be moderate.

**TABLE 1. NEONATAL AIRWAY PRESSURE STUDIES USING HIGH FLOW NASAL CANNULA**

<b>Study</b>	<b>Journal</b>	<b>Year</b>	<b># of Infants</b>	<b>Wt Range (gm)</b>	<b>Flow Range (L/min)</b>	<b>Conclusions of Airway Pressure</b>	<b>Relevant Circumstances</b>
Saslow <sup>8</sup>	J Perinatol	2006	18	580 – 1990	3 - 5	Not more than CPAP of 6 cmH <sub>2</sub> O	Esophageal manometry referenced to CPAP 6 cmH <sub>2</sub> O
Pyon <sup>9</sup>	PAS (abstract)	2008	8	< 2000	6 - 8	Not more than CPAP of 6 cmH <sub>2</sub> O	Esophageal manometry referenced to CPAP 6 cmH <sub>2</sub> O
Spence <sup>10</sup>	J Perinatol	2007	14		Up to 5	Intrapharyngeal pressure was 4.8 ± 0.5 cmH <sub>2</sub> O at 5 L/min	Mouth closed and nasal catheter
Wilkinson <sup>4</sup>	J Perinatol	2008	18	534 - 1868	2 - 8	Mean pharyngeal pressure of 5.3 cmH <sub>2</sub> O at 5 L/min	Nasal catheter
Kubicka <sup>11</sup>	Pediatrics	2008	27	200 - 3500	1 - 5	Highest oral cavity pressure recorded was 4.8 cmH <sub>2</sub> O	Mouth closed with snug prongs
Lampland <sup>2</sup>	J Pediatr	2009	15	1324 ± 424	1 - 6	Similar to CPAP of 6 cmH <sub>2</sub> O	Esophageal manometry referenced to CPAP 6 cmH <sub>2</sub> O

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