

**PRESSURES DELIVERED BY NASAL HIGH FLOW THERAPY DURING  
ALL PHASES OF THE RESPIRATORY CYCLE**

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## **Conflict of Interests**

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## **Abstract**

Nasal high flow oxygen therapy (NHF) and continuous positive airway pressure (CPAP) are modes of non-invasive respiratory support used to improve respiratory function in multiple patient groups. Both therapies provide positive pressure although this varies during the respiratory cycle. The purpose of this study was to measure and compare the airway pressure generated during different phases of the respiratory cycle in patients receiving NHF at various gas flows.

## **Methods**

Patients scheduled for elective cardiac surgery were approached and invited to participate in this study. Nasopharyngeal pressure measurements were performed using nasal high flow with gas flow rates of 30, 40 and 50 L/min. All measurements were performed in random order with patients breathing mouth closed.

## **Results**

Mean (SD) nasopharyngeal airway pressures of 1.4 (0.6), 2.2 (0.8) and 3.0 (1.0) were recorded at 30, 40 and 50 L/min using nasal high flow. Analyses also determined the mean peak expiratory and mean expiratory plateau pressures.

## **Conclusion**

This study describes the airway pressures generated by NHF. Expiratory pressures during NHF were higher than the mean pressures previously reported for this therapy. We believe this may account in part for the disproportional clinical effects seen with NHF.

**Keywords:** Airway pressure; Nasal high flow oxygen therapy; non-invasive ventilation; Optiflow<sup>TM</sup>; oxygen

## Introduction

Respiratory complications including hypoxia, sputum retention and basal lung atelectasis remain a leading cause of post cardiac surgery morbidity and can prolong hospital stay and increase costs.<sup>1</sup> Traditionally, therapy has consisted of the administration of oxygen and non-invasive ventilation using facemask continuous positive airway pressure (CPAP) to maintain adequate oxygenation in patients with inadequate respiratory function post-operatively. A recent novel therapy that is gaining widespread use in both the intensive care unit (ICU) and post-operative ward is nasal high flow oxygen therapy (NHF), in which heated and humidified blended oxygen and air is administered utilising flows of up to 60L/min delivered via a specially designed nasal interface.<sup>2-6</sup> NHF has been demonstrated to be easy to institute and comfortable to the patient, with excellent compliance with the therapy<sup>6,7</sup> A recent randomized controlled trial comparing NHF to high flow facemask oxygen therapy (HFFM) found more patients allocated to NHF were considered to be successful on their treatment ( $p = 0.006$ ) whilst a reduction in NIV rates in the NHF group ( $p=0.096$ ) was also described.<sup>2</sup> However, until recently there was little evidence explaining the likely mechanisms of action attributed to NHF, namely the provision of positive airway pressure, active humidification and naso-pharyngeal washout.<sup>8</sup> It has previously been demonstrated that NHF provides a low level, flow dependent positive airway pressure,<sup>5,9,10</sup> however the clinical effect often appears to be disproportional to the low pressures described. A common feature of all these studies is that the airway pressure reported at different NHF flow rates has been the mean pressure recorded over the whole of the respiratory cycle; however observation of the pressure waveform demonstrates significant variation in pressure during inspiration and expiration. It is plausible that the predominant benefits of positive

pressure occur during expiration, particularly in patients who are at risk of, or have established, atelectasis. It could be assumed that mean expiratory pressures may be responsible for preventing atelectasis and peak and mean expiratory pressures responsible for the re-expansion of collapsed areas.

This study aimed to quantify the pressures produced during the different parts of the respiratory cycle with NHF using various gas flows.

## **Methods**

This study was approved by the Northern X Regional Ethics Committee and registered with the Australian Clinical Trials Registry ([www.anzctr.org.au](http://www.anzctr.org.au) ACTRN12609000305224). Adult patients scheduled for elective cardiac surgery were invited to participate and written informed consent gained pre-operatively. Patients were excluded if contraindications to either NHF or NIV were present. Following surgery, and whilst still sedated and ventilated in the ICU post-operatively, a 10 French catheter was inserted into the nasopharynx via the nose. The catheter was secured in place and remained *in situ* overnight. Pressure measurements were performed once the participant was awake, extubated and sitting up in a chair the day after surgery. Placement of the pressure measuring catheter was first confirmed with a visual check to ensure the tip was positioned just below the uvula, and then also checked using end tidal CO<sub>2</sub> monitoring. If necessary the catheter was adjusted or suctioned to obtain a clear trace. The catheter was then connected to the Honeywell precision pressure transducer (PPT-0001 DWWW2VA-B, Honeywell International Ltd, NJ, USA) using a laptop computer interface. This methodology has previously been reported.<sup>9, 10</sup> The Optiflow™ system (MR880 heated humidifier, RT241 heated delivery tube, RT033/034 Optiflow™ nasal cannula, Fisher and Paykel Healthcare

Ltd, Auckland, New Zealand) was used to deliver humidified nasal oxygen and measurements were performed with gas flow rates of 30, 40 and 50 L/min (Figure 1). Measurements were performed in random order with patients breathing with mouth closed. The order of measurement was determined by Latin square, constructed in a Williams design, so that each treatment occurred once per patient.<sup>11</sup> This ensured random treatment allocation to each measurement and sequences were randomly allocated to patients square by square. A washout period was allowed between each treatment to ensure no carry over effect. At the end of the investigation, the nasopharyngeal catheter was removed and the patient continued on their original oxygen therapy. Nasopharyngeal pressure at each flow was recorded over one minute of breathing. Actual pressure was recorded in an Excel spread sheet at a resolution of 120Hz and waveforms of the pressure trace reconstructed from the data.

The mean nasopharyngeal airway pressure was determined by averaging the pressure over one minute – from the peak of inspiration of the first breath to the peak of inspiration of the last breath. This allowed the entire pressure profile of each breath within that minute to be included within the mean airway pressure calculation. Analysis of the inflection points of the airway pressure recordings allowed determination of the start of inspiration and expiration enabling the calculation of peak expiratory pressure, average expiratory pressure, average inspiratory pressure and average plateau pressure.

All data analysis was performed using Microsoft® Office Excel 2003. Data are presented as mean (SD).

## Results

15 patients scheduled for elective cardiac surgery participated in this study. Patient characteristics are described in Table 1. Thirteen patients had coronary artery bypass surgery while 2 patients had valvular surgery. All surgery was performed through a median sternotomy and involved cardiopulmonary bypass.

Table 2 presents the mean ( $\pm$  standard deviation) nasopharyngeal airway, expiratory plateau, peak expiratory, mean expiratory and mean inspiratory pressures recorded with nasal high flow. Mean (SD) nasopharyngeal airway pressures of 1.52 (0.6), 2.21 (0.8) and 3.1 (1.2) were recorded at 30, 40 and 50 L/min using nasal high flow. Analysis of the pressure generated during different parts of the respiratory cycle demonstrated that higher pressures are obtained during expiration as compared to other parts of the respiratory cycle, and that both the expiratory plateau and peak expiratory pressures are flow dependent (Table 2).

All individual patient measurements and mean nasopharyngeal pressures delivered are shown in Figure 2. Typical pressure profiles from one patient at increasing gas flows (NHF) are shown in Figure 3.

## **Discussion**

This study describes the airway pressures generated at three flow rates in patients receiving NHF and reports for the first time the pressure delivered during different phases of the respiratory cycle by NHF.

Previous work<sup>9,10</sup> has reported the mean pressure delivered by NHF across the whole of the respiratory cycle, however because these pressures are low (mean 2 - 4cmH<sub>2</sub>O) doubt has been raised about the clinical relevance of positive pressure as a proposed mechanism of effect of NHF.

Observation of the airway pressure waveforms produced during different phases of the respiratory cycle demonstrates variability with NHF, with higher pressures measured during the expiratory phases. It has been hypothesised that the provision of positive end expiratory pressure (PEEP) by NHF contributes to the reduction in work of breathing and improvement in oxygenation that has been found in other studies.<sup>5,6,12</sup>

This study has shown that both the peak and expiratory plateau pressures generated during NHF therapy are higher than the mean airway pressures previously reported and we suggest that this may help explain the clinical benefits seen with these devices. NHF at flows up to 50 L/min provides PEEP and peak expiratory pressures at significantly higher levels than the recorded mean pressure but these are still less than that recorded and delivered with facemask CPAP. We would suggest that in patients who require an escalation in respiratory support therapy NHF should be seen as a logical step between traditional oxygen therapy and facemask CPAP. Similarly NHF is a logical intermediary step when weaning patients from higher positive airway pressure systems to low flow oxygen therapy.<sup>13</sup>

It has also been proposed that the high flows generated by NHF act as a resistance to exhalation and result in a clinically significant positive airway pressure when the patient breathes with mouth closed.<sup>14</sup> This pressure effect may then be transmitted down the airways to the alveoli assisting in re-expansion of atelectatic areas. This increased resistance during expiration creates an expiratory positive airway pressure (EPAP) not dissimilar to that employed in devices for the management of obstructive sleep apnoea.<sup>15</sup> This increased positive airway pressure may be responsible for the improved results seen when NHF is employed for hypoxaemic respiratory distress.<sup>2,12</sup>

#### Limitations



This study was designed to measure respiratory pressures not physiological outcomes so no data was collected to show changes in respiratory rate, SpO<sub>2</sub>, minute ventilation or lung volumes. There were a small number of females recruited into this study due to the convenience sampling technique employed. Therefore these results may not be entirely applicable to female patients and we were unable to test for gender differences, however it has been noted before that female subjects experience significantly higher airway pressure than males using Optiflow™.<sup>16</sup> Also, due to the nature of the patient population available, the cohort only involved adult patients following cardiac surgery so the results of this study may not be generalisable to all patients such as paediatrics.

### **Conclusion**

This study describes the airway pressures generated by NHF over the whole of the respiratory cycle and demonstrates that the pressure generated with NHF during expiration is higher than the mean airway pressure recorded over the whole respiratory cycle. Although NHF is unable to provide pressures similar to CPAP this study has demonstrated that both the mean and peak expiratory pressures are in a range that is likely to have a clinical effect and thus we believe that the provision of positive airway pressure is one of the mechanisms of action responsible for the clinical benefits seen with NHF. This study adds to the body of evidence relating to this novel respiratory support therapy, however further work is required to elucidate further the mechanisms of action of NHF including its effects on work of breathing, changes in lung volumes, oxygenation and intrathoracic pressure to truly support that NHF provides some form of lung recruitment.

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Legend of figures.

Figure 1. Pressure measuring set-up with Optiflow™ nasal high flow.

Figure 2. Individual and mean nasopharyngeal airway pressures delivered by nasal high flow.

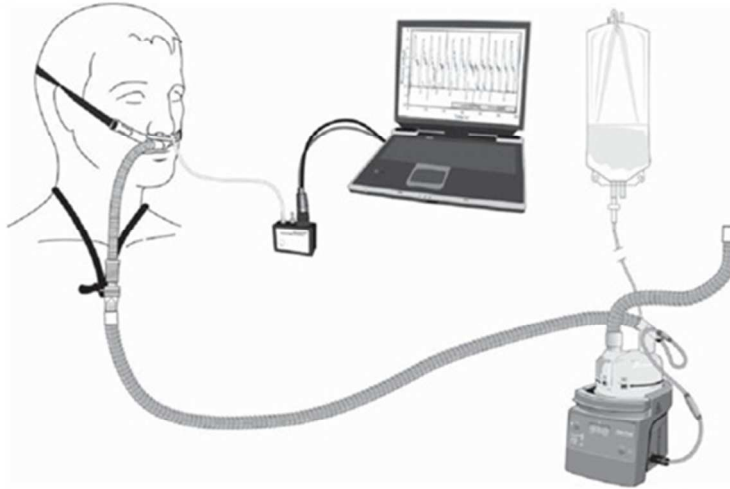
Figure 3. Pressure profiles from one patient at increasing gas flows when using nasal high flow.

**Table 1: Patient Characteristics.**

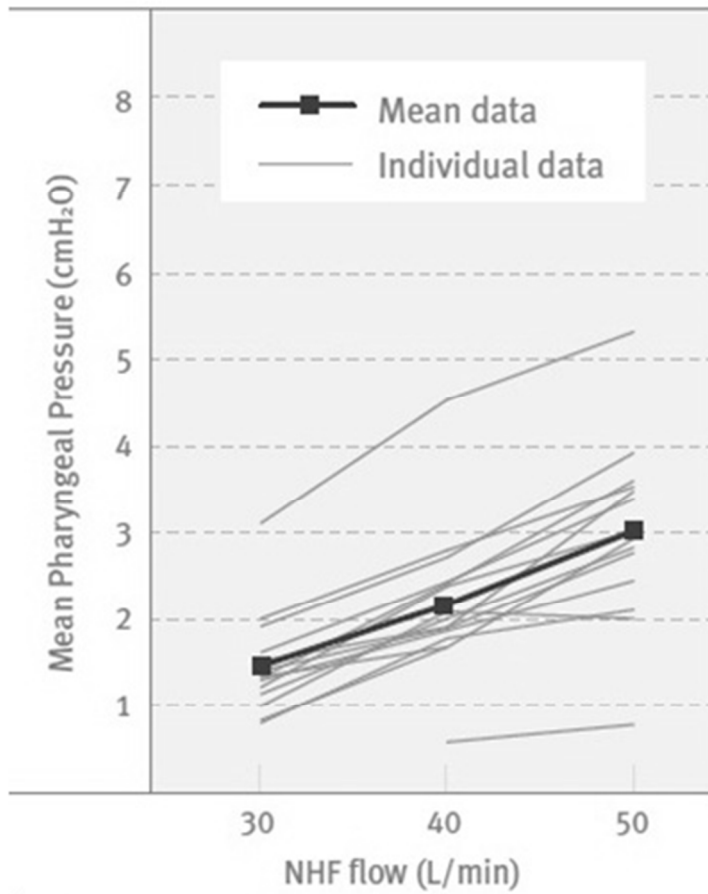
<i>n=15</i>	
Age - mean (years)	59.5
SD	10.6
Gender	
Male	14
Female	1
Height - mean (cms)	173
SD	4
Weight - mean (kgs)	85.1
SD	17
BMI - mean	29
SD	5
Ethnicity	
NZ European	10
NZ Maori	3
Pacific Island	2

**Table 2. Airway pressures delivered with nasal high flow.**

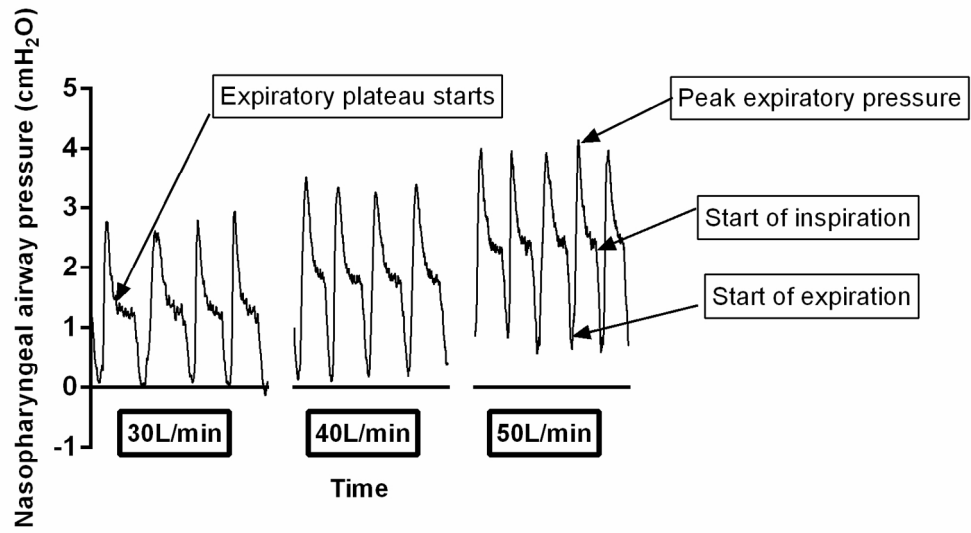
<b>Flow</b>	<b>Mean airway pressure (cmH<sub>2</sub>O)</b>	<b>SD</b>	<b>Average plateau pressure (cmH<sub>2</sub>O)</b>	<b>SD</b>	<b>Peak Expiratory pressure (cmH<sub>2</sub>O)</b>	<b>SD</b>	<b>Average expiratory pressure (cmH<sub>2</sub>O)</b>	<b>SD</b>	<b>Average inspiratory pressure (cmH<sub>2</sub>O)</b>	<b>SD</b>
<b>30 L/min</b>	1.52	0.6	1.71	0.73	3.01	1.18	2.1	0.83	0.55	0.38
<b>40 L/min</b>	2.21	0.8	2.48	0.94	3.81	1.45	2.88	1.04	1.11	0.51
<b>50 L/min</b>	3.10	1.2	3.41	1.24	4.86	1.79	3.81	1.33	1.77	0.69



163x108mm (96 x 96 DPI)



133x123mm (96 x 96 DPI)



141x80mm (300 x 300 DPI)