

Use of venturi entrainment to deliver nasal high flow oxygen

Gerald L. Wong, Mark E. Finnis

Abstract

Objective: To evaluate the use of an adjustable venturi device with standard wall oxygen supply to deliver nasal high flow oxygen.

Design: We set up a circuit using a standard 15 L/min oxygen rotameter connected to a wall outlet, 2 m standard oxygen tubing, an adjustable venturi device, humidification chamber and nasal high flow circuit and cannulae. Delivered FiO₂ and total gas flow rates were measured over a range of oxygen flow rates and venturi settings. The study was conducted in two parts - a bench-top study to define the usable range and using a human subject to assess loaded performance of the circuit.

Key words: Nasal high-flow therapy, oxygen, venturi

Introduction

High flow nasal oxygen (NHF) is used to deliver supplemental oxygen, particularly for patients intolerant of conventional masks or those requiring a higher FiO₂ than can be achieved by face mask; also, to provide a small level of PEEP to patients where work of breathing may be improved.

High flow oxygen is commonly provided using either an oxygen-air blender or dual high flow rotameters, both of

Setting: Royal Adelaide Hospital Intensive Care Unit.

Participants: One study author.

Results: A clinically useful range of total flow rates (30-50 L/min) and delivered FiO₂ (0.4-0.6) was achieved using the circuit described. The variation in performance seen with loading of the circuit was clinically insignificant. We have calibrated this 'Fisher and Paykel' adjustable venturi device for use with the Fisher and Paykel heater chamber and circuit.

Conclusion: We demonstrated that nasal high flow oxygen can be delivered in a clinically useful and predictable manner using a venturi entrainment device.

which require high pressure wall outlets of both gases. It can also be delivered by using devices that entrain a fixed proportion of room air.

In our institution, air outlets are not available in most wards and high flow oxygen is therefore unable to be delivered in a ward setting.

This study aimed to assess the performance of a humidified high flow nasal cannula circuit using a venturi device attached to a wall oxygen outlet with a standard low flow 15 L/min rotameter.

Materials and methods

A test circuit was constructed as shown in **Figure 1**. A standard 15 L/min rotameter, connected to a wall oxygen outlet, was connected to an adjustable Fisher and Paykel RT008 venturi

From Royal Adelaide Hospital, North Terrace, Adelaide, Australia (Gerald L. Wong and Mark E. Finnis)

Address for correspondence:

Gerald Wong

Intensive Care Unit, Royal Adelaide Hospital

North Terrace, Adelaide, SA 5000.

Tel: +61 8 8222 5649

Fax: +61 8 8222 2826

Email: geraldwong@xtra.co.nz

valve (Fisher and Paykel Healthcare Corporation Limited) via a 2 m length of oxygen tubing. The venturi was placed at the inlet port of a Fisher and Paykel MR 850 humidifier and MR 290 Autofeed humidification chamber (Fisher & Paykel Healthcare Corporation Limited). The outlet port of the chamber was connected in series to an oxygen analyzer (Datex Ohmeda 5120 Louisville, Colorado USA), High Performance RT spiral wire breathing circuit, a flow-meter (Datex Ohmeda 5420 volume monitor Louisville, Colorado USA) and then nasal high flow cannula (Optiflow™ - Fisher & Paykel Healthcare Corporation Limited). The flow-meter was placed in this distal position to prevent “rain-out” interfering with flow measurement.

The study was performed in two parts. Firstly, a bench study was done to define the performance parameters of the system in isolation and determine the potentially usable range of FiO2 and delivered total gas flows. We tested each FiO2 setting available on the venturi device (28, 29, 30, 40, 50, 60, 70, 80, and 90%) at oxygen flow rates from 3 to 15 L/min, in 2 L/min increments. We pre-determined that a practical range for total delivered flow would be 30 to 55 L/min, in order to achieve some level of PEEP when clinically applied.

Secondly, the high flow nasal cannulae were placed on a test subject (author G.W.) and the system retested using the range of FiO2 and flows as determined in the first part of the study (**Table 1**). This was required as the performance of any venturi device, in terms of entrainment ratio and therefore FiO2, will be influenced by the down-stream circuit resistance.

Statistical analysis

No assumptions were made with regard to data distribution and all group-wise comparisons were made using appropriate non-parametric tests (Mann-Whitney U or paired sample Wilcoxon signed rank tests). Linear regression was performed to approximate actual circuit performance. All analyses were performed using Minitab 15® statistical software.

Results

Over the range of driving oxygen flow rates tested, for

each FiO2 setting on the venturi device, we measured the delivered FiO2 and total gas flows as shown in **Figures 2 and 3** respectively. The delivered FiO2 remained virtually constant over the range of flow rates for each of the venturi settings tested. Delivered FiO2 was systematically higher than the venturi FiO2 setting ($p < 0.0001$), with this effect being maximal at low venturi FiO2 settings (**Figure 2**). This reflected a lower than expected entrainment ratio when using the test circuit.

As expected, total flow rates (**Figure 3**) were inversely related to the venturi FiO2 setting. The measured total flow was systematically less than predicted ($p < 0.0001$), also confirming lower than predicted air entrainment.

Consequently, at the total flow rates required (30-55 L/min), higher FiO2 levels were not achievable using this air entrainment system. This was not seen as problematic, as higher concentrations of oxygen are not deemed appropriate for general ward use; patients requiring high flow oxygen at greater than 60-70% should ideally be transferred to a high-dependency area.

The effect of loading the circuit with a test subject resulted in a further reduction in total flow. While this was statistically significant ($p = 0.001$), clinically the effect was small with a median difference of 2.3 (95 CI: 1.55-2.95) L/min. Similarly, the effect upon measured FiO2 was small, with a median increase 1.3 (95 CI: 0.82-1.68) %.

Whilst these data show the venturi used was poorly calibrated for test circuit, both total gas flow and delivered FiO2 were clearly determined by the venturi FiO2 setting and O2 supply flow. Regression analysis for Total Flow (Unloaded) versus O2 (L/min) and Venturi FiO2 rendered a regression equation:

$$\begin{aligned} \text{Total Flow Unloaded} &= 38.6 + 2.82 \\ \text{O}_2 \text{ (L/min)} &- 0.833 \text{ Venturi FiO}_2 \\ \text{R-Sq} &= 92.1\% \end{aligned}$$

And regression for measured FiO2 versus O2 (L/min) and Venturi FiO2 rendered:

$$\begin{aligned} \text{Measured FiO}_2 &= 25.3 + 0.584 \\ \text{O}_2 \text{ (L/min)} &+ 0.471 \text{ Venturi FiO}_2 \\ \text{R-Sq} &= 96.1\% \end{aligned}$$

Discussion

We found that nasal high flow oxygen, over a given range, can be delivered using a venturi entrainment device connected to a wall oxygen outlet via a standard 15 L/min oxygen flow meter.

This arrangement allows delivery of high flow oxygen without the use of dual high flow rotameters or a blender, thus enabling potential cost savings. In addition, high flow oxygen can be delivered in locations without high pressure air outlets.

High flow oxygen has a role in hospitalized patients who require a high FiO₂ with low level PEEP. (1) It can be delivered via nasal cannulae in those whom masks are poorly tolerated, and have been shown to improve oxygenation, work of breathing, comfort, and nutrition. (2,3) High flow oxygen is generally delivered using a warmed, humidified circuit for comfort and to prevent excessive drying of the respiratory tract. Flows greater than 6 L/min via nasal cannulae are poorly tolerated because of nasal dryness, crusting, and epistaxis. (3)

This study evaluated the Fisher and Paykel RT008 Venturi device with the Fisher and Paykel humidifier and circuit and found a range of oxygen flow rates and FiO₂ values that would deliver practical fresh gas flow rates and inspired oxygen concentrations usable in hospitalized patients. Using oxygen flow rates between 7 and 15 L/min and venturi settings between 28-50%, we demonstrated total flow rates between 30 and 50 L/min and FiO₂ between 40-60%. Outside these settings, total results were less predictable as shown by the outlier variables in the analysis.

As expected, regression analysis showed that oxygen flow rates and venturi settings were predictors of total flow and delivered FiO₂ with R-squared values greater than 0.9.

Although the decrease in total flow with a subject attached to the circuit reached statistical significance, the difference is likely to be clinically insignificant. Nasal cannulae are a variable performance oxygen delivery system. Actual FiO₂ is determined by a number of factors including minute ventilation and breathing pattern (eg mouth breather vs nose breather). In addition, entrainment systems are sensitive to backpressure occurring downstream which may lead to an increase in FiO₂ and decrease in total flow. Delivered flow rates would be expected to vary under differing loading conditions, though, the clinical significance of this variability is unknown. We are therefore planning a follow-on study, assessing the variability in performance on a range of clinical subjects.

We are not aware of any other study which has calibrated an adjustable venturi device for delivering nasal high flow oxygen. Given that the humidification chambers and circuits used in this study are routinely used in ventilated patients in our institution, this method has the benefit of not requiring either dual high flow meters or air-oxygen blenders, and thus potential cost savings. The total flow rates between 30 and 50 L/min and delivered FiO₂ of between 40-60% represents clinically useful ranges applicable to patients outside of intensive care or high dependency units. Indeed those patients requiring a greater FiO₂ than 60% may be more suited to a higher acuity area.

Based on these results, we intend to conduct further study to determine the variability on flow rates between different subjects.

However, the results of this study suggest that this arrangement can be safely applied to patients who are suitable for nasal high flow oxygen therapy and where conventional methods for delivering this are not available.

Table 1. Usable range of total flow between 30-55 L/min

O2 (L/min)	Venturi FiO2	Predicted flow*	Measured FiO2	Entrainment ratio	Total flow unloaded	Total flow loaded
7	28	79	43	3.63	32.4	29.8
9	28	102	44	3.51	40.6	43.8
11	28	124	45	3.37	48.1	47.8
13	28	147	46	3.13	53.7	51.7
7	29	69	43	3.56	31.9	28
9	29	89	44	3.51	40.6	39.6
11	29	109	46	3.25	46.7	43.3
13	29	128	47	2.92	50.9	47.7
15	29	148	48	2.57	53.5	48.6
7	30	61	44	3.31	30.2	28.2
9	30	79	45	3.44	40	38.8
11	30	97	46	3.27	47	44.3
13	30	114	47	2.97	51.6	48.3
9	40	37	48	2.73	33.6	30.9
11	40	46	49	2.55	39	38.4
13	40	54	51	2.38	43.9	41.4
15	40	62	51	2.06	45.9	42.2
13	50	35	58	1.64	34.3	33
15	50	41	59	1.39	35.9	33.6

Legend: *Predicted flow = $V_T = V_{O_2} + \frac{V_{O_2} \times (1 - FiO_2)}{(FiO_2 - 0.21)}$ by conservation of mass

Figure 1. Basic circuit diagram

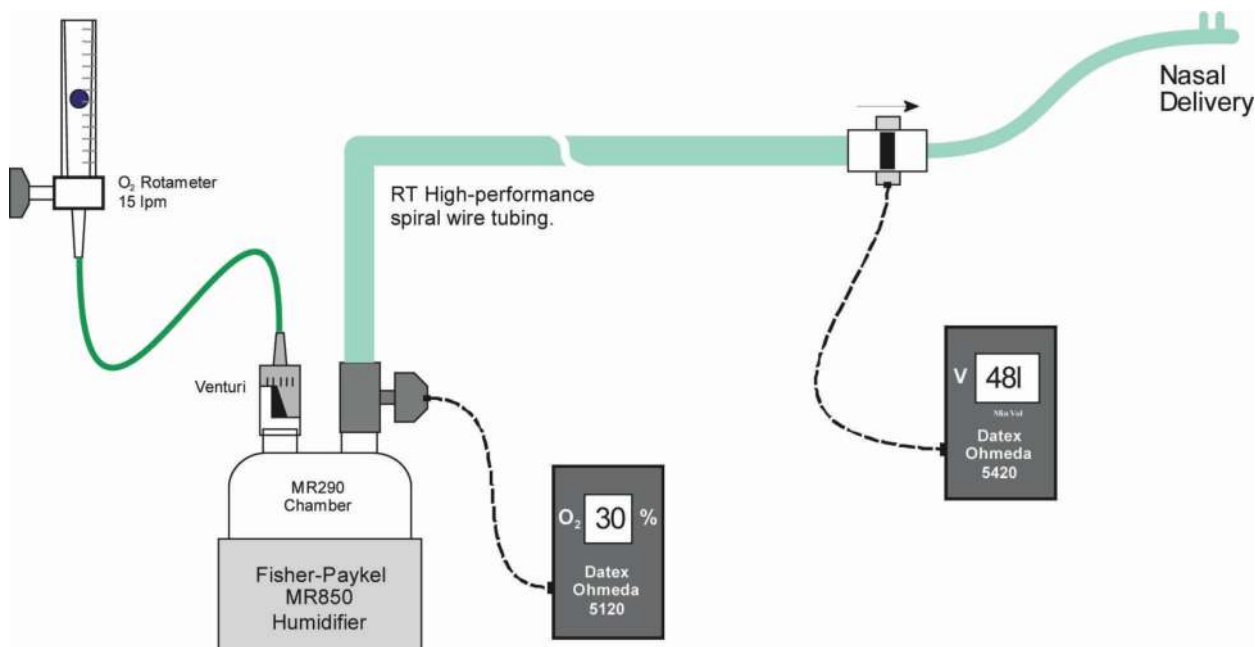


Figure 2. Delivered FiO2 vs O2 flow rate at each venturi setting, eg 'V28' = venturi FiO2 setting = 0.28

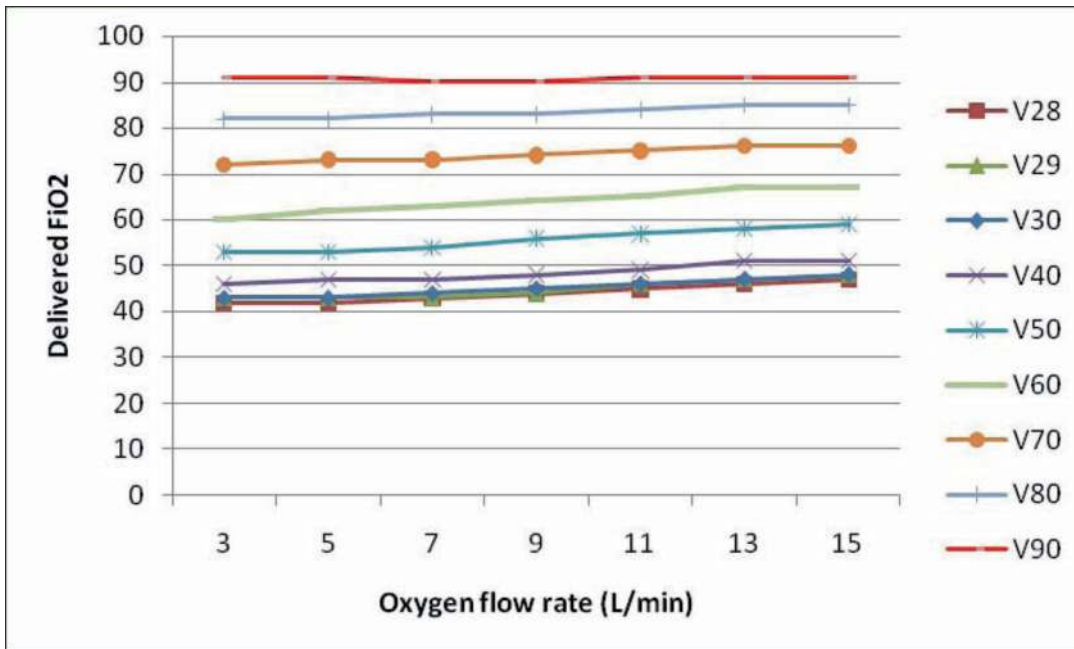
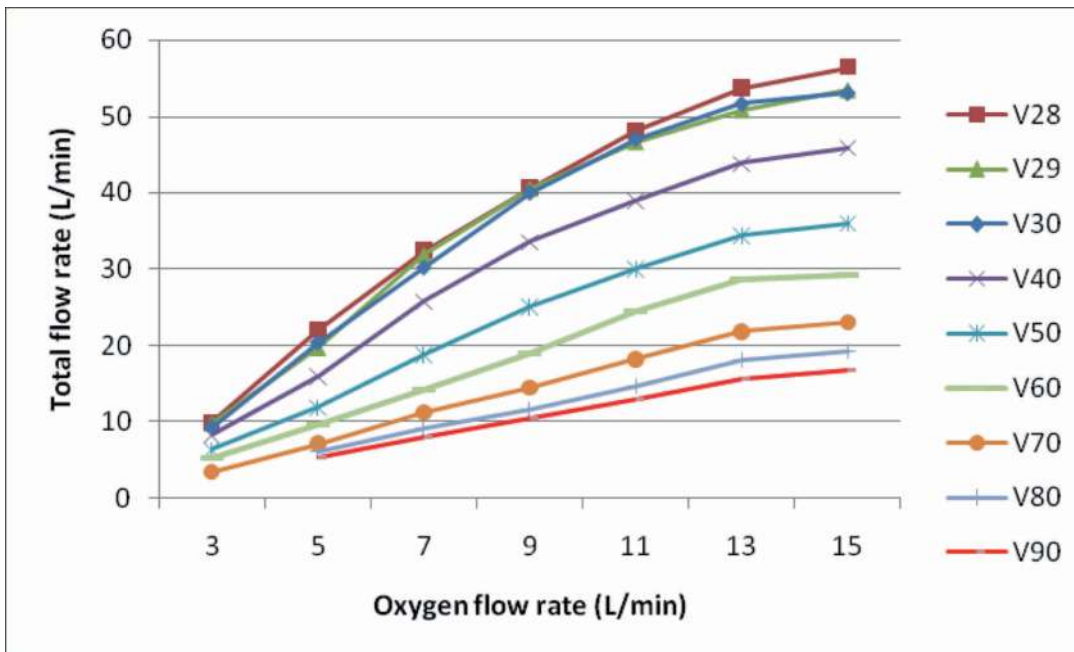


Figure 3. Total flow vs oxygen flow rate at each venturi setting



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