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Humidification performances of two high flow nasal cannula devices: a bench study

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Abstract

Background

Delivering heated and humidified medical gas at 20 – 60 L/min, high flow nasal cannula (HFNC) creates low level of PEEP, and ameliorates respiratory mechanics. It has become a common therapy for patients with respiratory failure. However, independent measurement of heat and humidity during HFNC and comparison of HFNC devices are lacking.

Method

We evaluated 2 HFNC (AIRVO™ 2 and Optiflow™ system) devices. Each HFNC was connected to simulated external nares using the manufacturer's standard circuit. The AIRVO™ 2 outlet-chamber temperature was set at 37°C. The Optiflow™ system incorporated an O_2/air blender and a heated humidifier, which was set in 40°C /–3. For both systems, HFNC flow was tested at 20, 40 and 50 L/min. Simulating spontaneous breathing using a mechanical ventilator and TTL test lung, we tested tidal volumes (V_T) of 300, 500 and 700 mL, and breathing frequencies of 10 and 20 breath/min. The TTL was connected to the simulated external nares with a standard ventilator circuit. To prevent condensation, the circuit was placed in an incubator maintained at 37°C. Small, medium and large nasal prongs were tested. Absolute humidity (AH) of inspired gas

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was measured at the simulated external nares.

Results

At 20, 40, and 50 L/min of flow, respective AH values for the AIRVO™ 2 were 35.3±2.0, 37.1±2.2 and 37.6±2.1 mg/L, and for the Optiflow™ system, 33.1±1.5, 35.9±1.7 and 36.2±1.8 mg/L. AH was lower at 20 L/min of HFNC flow than at 40 and 50 L/min ($P<0.01$). While AH remained constant at 40 and 50 L/min, at 20 L/min of HFNC flow, AH decreased as V_T increased for both devices.

Conclusions

During bench use of HFNC, AH increased with increasing HFNC flow. When the inspiratory flow of spontaneous breathing exceeded the HFNC flow, AH was influenced by V_T. At all experimental settings, AH remained above 30 mg/L.

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Introduction

Oxygen therapy is the first line treatment for patients who suffer organ dysfunction [1-3], and nasal cannula is commonly used low-flow oxygen delivery. This means of delivery is typically used for stable patients, for whom the inspired fraction of oxygen (F_IO_2) may vary according to breathing pattern. Oxygen flow is usually 1 – 6 L/min. Administration of more than 6 L/min does not greatly improve F_IO_2 and leads to nasal dryness, bleeding, and other discomfort to the patient [4]. Simple oxygen mask is used to deliver higher flow 5 to 12 L/min. When it does not meet patient demand, room air is drawn around the mask. F_IO_2 varies mask fitting, delivered flow, and minute volume of patient. When flow is low, carbon dioxide is rebreathed.

Recently, in intensive care units, high flow nasal cannula (HFNC) therapy has become common for patients with unstable respiratory function [5]. HFNC can deliver up to 60 L/min of heated and humidified medical gas and F_IO_2 can be adjusted using a wide bore nasal cannula. HFNC therapy is considered to create low level of positive end-expiratory pressure (PEEP) [6, 7] and to reduce dead space. While effects on oxygenation, carbon dioxide (CO_2) elimination, and respiratory mechanics have been reported [8-11], no independent measurements on heat and humidity delivered during HFNC have been published. In the field of humidification, it is important to provide

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independent measurements of device performances, since discrepancies may exist between data provided by the manufacturers and bedside clinical data [12]. We carried out this bench study to evaluate humidification performance of HFNC devices under various spontaneous breathing patterns and with different prong sizes.

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Materials and Methods

We evaluated two types of HFNC (AIRVO™ 2, and Optiflow™ system, Fisher & Paykel, Auckland, NZ). In the AIRVO™ 2, chamber-outlet temperature was set at 37°C. The Optiflow™ system incorporated an O_2/air blender and a heated humidifier (MR850, Fisher & Paykel, Auckland, NZ). The MR850 was set in invasive mode (40°C/–3). For both systems we tested HFNC flow 20, 40 and 50 L/min. F_IO_2 was set at 0.21 for both devices. Spontaneous breathing (SB) was simulated using a mechanical ventilator (Puritan-Bennett 840, Covidien, Carlsbad, CA) and TTL test lung (TTL model 1601, Michigan Instruments, Grand Rapids, MI).To simulate SB, the muscle and lung compartment of the test lung were connected, then the Puritan-Bennett 840 inflated the muscle compartment, and the lung compartment inspired medical gas delivered via HFNC and ambient air. One-way valves prevented mixing of inspired and expired gases. Compliance of the TTL test lung was 0.05 L/cmH_2O and resistance was 5 cmH_2O/L/s. We tested tidal volumes (V_T) of 300, 500 and 700 mL, and breathing frequencies of 10 and 20 breath/min. Inspiratory time was set at 1 sec with square waveform and it resulted in 18, 30 and 42 L/min of SB inspiratory flow. Before experimental testing, a ventilator self-test was performed.

HFNC creates positive end-expiratory pressure (PEEP) and increases residual

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volume in the lung compartment. We measured the end-expiratory pressure of the lung compartment and to keep the residual volume of the muscle compartment at the same level as the lung compartment, set corresponding levels of PEEP on the Puritan-Bennett 840. To confirm V_T delivered to the lung compartment, flow to the lung compartment was measured using a pneumotachometer (4700 series, 0-160 LPM, Hans Rudolph, Inc., Shawnee, KS) with a differential pressure transducer (TP-602T, ±5 cmH_2O, Nihon Kohden, Tokyo, Japan).

We made two holes in polyvinyl chloride cylinder to simulate external nares (Fig. 1). Into these holes we inserted and tested small, medium and large nasal prongs: OPT842, OPT844, and OPT846 with the AIRVO™ 2; and OPT542, OPT544, OPT546 with the Optiflow™. The nasal prongs were connected to the manufacture's standard circuit (900PT501 for the AIRVO™ 2; and RT202 for the Optiflow™). The external nares were connected to the TTL test lung via a standard ventilator circuit (Smoothbore tube 5000000, Intersurgical Ltd., Berkshire, UK). To prevent condensation, the circuit was placed in an incubator (V-2100G, No. 8090508, ATOM Medical, Tokyo, Japan) in which the temperature was maintained at 37°C. All experiments were performed in an air-conditioned room.

After each experimental setting was changed, we allowed at least 30 minutes for

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stabilization. Temperature, relative humidity (RH) and absolute humidity (AH) of inspired gas downstream of the external nares were measured using a moisture sensor (Moiscope, Senko Medical, Tokyo, Japan; capacitance-type, response time 3 s in the range 40% – 100%). The hygrometer was calibrated at two points by using a cooler/heater water source (HHC-51, Senko Medical, Tokyo, Japan). Because condensation on sensor surfaces compromises the accuracy of humidity measurement, the sensor was withdrawn from the circuit during stabilization periods; after insertion for measurement, we monitored temperature, RH and AH for 10 min, and after confirming the constancy of the values, we recorded temperature, RH, and AH for the final 5 min. All signals were processed through an analog/digital converter and saved on a computer at 50 Hz/channel using data acquisition software (WinDaq, Dataq Instruments, Akron, OH). For each experimental setting we measured temperature and AH for 5 breaths. The results were expressed as mean ± SD.

Analysis of variance was performed using repeated measures ANOVA. All statistical tests were two-sided and a P value of <0.01 was considered statistically significant. All statistical analysis was performed using commercial software (SPSS 11.01, SPSS, Chicago, IL).

RESPIRATORY CARE Paper in Press. Published on December 24, 2013 as DOI: 10.4187/respcare.02932

Result

AH was 36.5±2.3 mg/L with the AIRVO™ 2, and 35.1±2.2 mg/L with the Optiflow™ system ($P<0.01$); at 20, 40, and 50 L/min respectively, AH with the AIRVO™ 2 was 35.2±2.6, 36.9±2.2 and 37.4±2.1 mg/L, and with the Optiflow™, 33.1±1.5, 35.9±1.7 and 36.2±1.7 mg/L (Fig. 3). With both systems, AH was significantly higher at 40 and 50 L/min than at 20 L/min ($P < 0.01$). AH remained the same at 40 and 50 L/min.

At 300, 500, and 700 mL of V_T respectively, AH with the AIRVO™ 2 was 35.6±1.9, 36.9±2.0 and 37.1±2.6 mg/L and, with the Optiflow™, 34.7±1.9, 35.3±1.9 and 35.3±2.7 mg/L. While V_T affected AH at 20 L/min HFNC flow (Fig. 3), at 40 and 50 L/min of HFNC flow, AH remained the same at 300, 500 and 700 mL of V_T. As breathing frequencies increased, AH increased ($P < 0.01$). Prong size did not affect humidification for both devices.

Throughout the protocol AH and the temperature of ambient air was 12.9±1.5 mg/L and 25.6±0.5°C.

RESPIRATORY CARE Paper in Press. Published on December 24, 2013 as DOI: 10.4187/respcare.02932

Discussion

In this first study to evaluate humidification performance under various spontaneous breathing patterns during HFNC, we found AH was above 30 mg/L at all tested settings.

For face mask administration, Chanques et al previously reported median AH was 29.7 (24.4 – 30.6) mg/L [13]; AH in the present study was higher. In their study, median flow was 7.8 (5.1 – 10.9) L/min, which was less than HFNC flow in the present study. In our experiment, we tested HFNC flow at 20, 40 and 50 L/min. Assuming that all delivered gas is inspired, humidity would depend on the inspiratory flow of SB and HFNC flow. When inspiratory flow is less than HFNC flow, patients would inspire only the gas delivered via HFNC, and humidification would depend almost entirely on the humidity of delivered gas. If inspiratory flow is greater than HFNC flow, patients would inspire both delivered gas and room air. SB inspiratory flow, respectively, was 18, 30, and 42 L/min at of V_T 300, 500, and 700 mL. Consequently, when HFNC flow is 20 L/min, inspiratory flow would be greater than HFNC flow at V_T 500 and 700 mL. We did, in fact, find with 20 L/min of HFNC flow that AH was lower at 500 and 700 mL of V_T than at 300 mL of V_T. Meanwhile, with 40 and 50 L/min of HFNC, humidification did not differ according to V_T, because the flow was similar to or greater than SB

RESPIRATORY CARE Paper in Press. Published on December 24, 2013 as DOI: 10.4187/respcare.02932

inspiratory flow. Chikata et al, simulating high-flow oxygen for tracheostomized patients in a bench study, reported findings similar to the present study; AH decreases as V_T increases [14].

It is also necessary to ensure adequate humidification of the gas delivered via HFNC. Chanques et al compared bubble and heated humidifiers [13]. With a heated humidifier, AH was twice higher than with a bubble humidifier. That study also used an MR850, which comprises a humidification chamber and a heated-wire circuit with 22 mm diameter tubing; the heated wire was set to maintain proximal temperature at 34°C and chamber temperature at 31°C. Using the same heated humidifier for the Optiflow™, our proximal temperature setting was 40°C and chamber setting was 37°C. These setting differences enabled higher inspiratory AH in the present study. For the AIRVO™ 2 we set only the chamber temperature, which was 37°C. The AIRVO™ 2 servo-controls the proximal temperature at around 40°C. In this way we obtained similar, higher than previously reported, AH values with the AIRVO™ 2 and with the Optiflow™.

AH was higher with the AIRVO™ 2 than with the Optiflow™. As described above, temperature control mechanism differs between the devices, and it may cause higher AH with the AIRVO™ 2. In addition, AIRVO™ 2 measures ambient temperature

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because it uses ambient air, while the manufacturer does not reveal algorithm to control gas temperature by measuring ambient temperature. Another possibility was volume of water chamber. AIRVO™ 2 contains larger volume of water, and it means more heat quantity.

Aside from being a bench study, our experiment was limited in other ways. For example, we tested only two HFNC devices, both from the same manufacturer, because they are the only ones currently available in Japan. We chose 20, 40, and 50 L/min of HFNC flow because they are in the range commonly selected when using these devices. Oto et al have reported on humidification and mouth dryness during non-invasive positive pressure ventilation (NPPV) [15]. Measuring AH inside face-masks during NPPV, they found AH varied in the range from 23.1 to 33.3 mg H_2O/L. If patients breathe through the mouth, they inspire more ambient air. Moreover the V_T of human beings varies [16], and AH might even vary breath-by-breath in clinical patients. In HFNC therapy, flow is delivered at a constant rate, and AH of delivered gas might be more stable than with NPPV. We cannot assume, however, HFNC always provides more stable humidification: results from our bench test cannot be directly applied to clinical settings. We firmly fixed the nasal prongs into the simulated external nares. In real life, the prongs usually move frequently. The present study was done only

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at F_IO_2 0.21. Optiflow™ uses only medical gases and air and oxygen are mixed upstream of water chamber, and AH is not influenced by F_IO_2. On the contrary, AIRVO™ 2 uses ambient air, and dry oxygen is added upstream of water chamber. Under high F_IO_2, AH could decrease. We set invasive mode of MR850 with the Optiflow™. Vapor output is different between the invasive and non-invasive modes, and AH must be lower in non-invasive mode.

In conclusion, we bench-tested inspiratory gas humidification during HFNC therapies with a simulated SB. At all experimental settings, AH was above 30 mg/L. During bench use of HFNC, AH increase with increasing HFNC flow. Although SB inspiratory flow exceeded HFNC flow, AH was influenced by V_T, humidification is sufficient for patients with SB at 20 – 50 L/min of HFNC flow with the devices investigated in the present study.

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RESPIRATORY CARE Paper in Press. Published on December 24, 2013 as DOI: 10.4187/respcare.02932

Figure legends

Fig 1. Photos of external nares

Left: To simulate external nares, two holes were opened in a polyvinyl chloride cylinder.

Right: Medium prongs attached to of high flow nasal cannula inserted into the simulated external nares. During experiment, prongs were secured on the nares using tape.

Fig 2. Experimental set up

A ventilator and TTL test lung were used to simulate spontaneous breathing. When a ventilator sends gas to the muscle compartment, the lung compartment attached to it starts inspiration. During simulated inspiration, ambient air is drawn into the lung compartment through the hygrometer. When the expiratory phase starts, gas in the lung compartment is expired to ambient space. We modeled external nares, which were connected to the simulated trachea. Each HFNC was connected to the simulated external nares using the manufacturer's standard circuit. The AIRVO™ 2 was set at 37°C and the Optiflow™ was set to 40°C at distal end of the breathing circuit and 37°C at the chamber outlet. The simulated trachea was placed in an incubator. To prevent condensation, the internal temperature of the incubator was maintained at 37°C.

RESPIRATORY CARE Paper in Press. Published on December 24, 2013 as DOI: 10.4187/respcare.02932

One-way valves were connected on the limb of the simulated trachea to separate inspiratory and expiratory gases.

Fig 3. Effects of flow and tidal volume on AH

At HFNC flow 20 L/min, when V_T increased from 300 to 700 mL, AH decreased; At HFNC flow 40 and 50 L/min, AH did not vary according to V_T.

RESPIRATORY CARE Paper in Press. Published on December 24, 2013 as DOI: 10.4187/respcare.02932

Fig 1. Simulated external nares with cannula

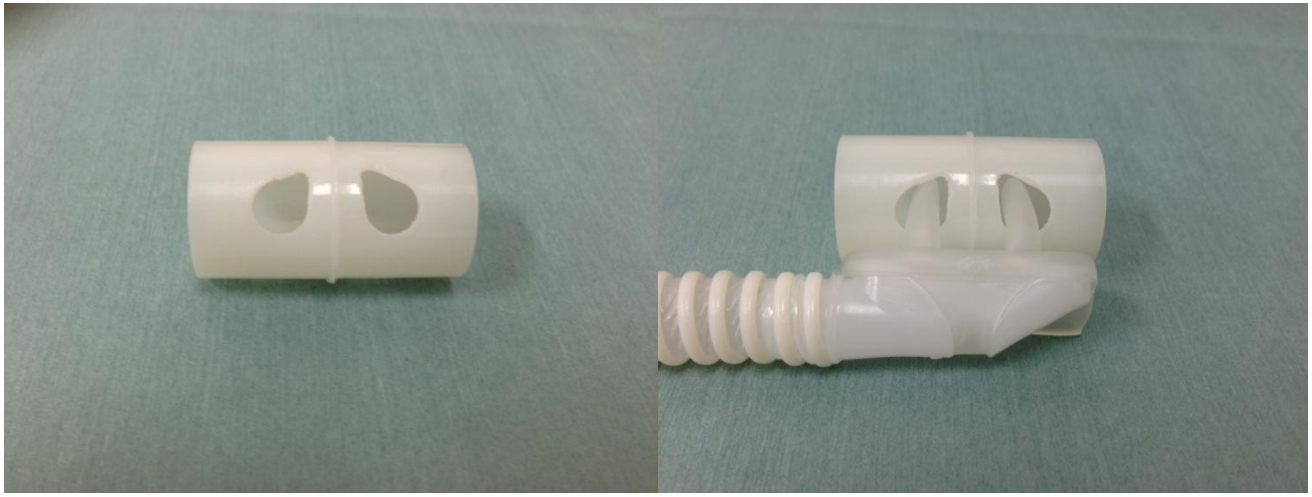

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Fig 2. Experimental set up

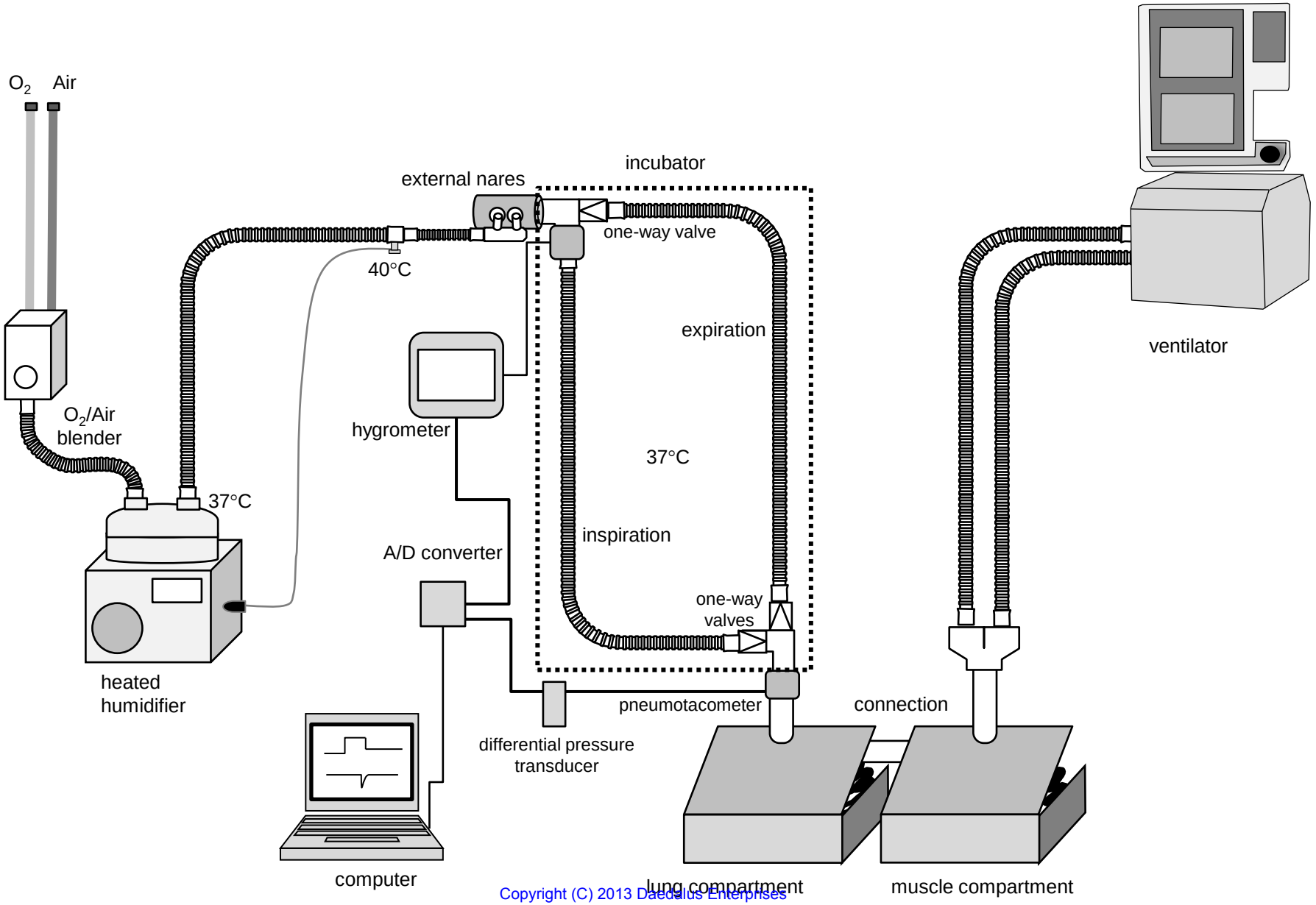

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Fig 3. Effects of flow and tidal volume on AH