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Right Versus Left Prong Nasal Cannula Flow Delivery and the Effects of Nasal Cycling on Inspired F_{IO_2} in an Adult Anatomic Model

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BACKGROUND: Nasal cycling may present negative consequences for oxygen-dependent patients using a nasal cannula. This study investigates the effects of nasal cycling on the delivered F_{IO_2} via nasal cannula in an anatomic model following a baseline study comparing right and left prong nasal cannula oxygen flow delivery. METHODS: Flow from right and left nasal cannula prongs were measured simultaneously using thermal mass flow meters while delivering 0.5–6-L/min oxygen for 5 nasal cannulas from different manufacturers. An adult mannikin head with an anatomically correct upper airway was connected to a QuickLung Breather test lung. Nasal cannula-delivered F_{IO_2} was recorded using a polarographic oxygen analyzer with naris occlusion simulated by inserting a 5.0 endotracheal tube into the naris and inflating the endotracheal tube cuff. Data were recorded with both nares open, for right naris occluded and left naris patent, and for left naris occluded and right naris patent at 0.5–6 L/min. RESULTS: A paired *t* test demonstrated statistical differences between right and left nasal cannula prong oxygen flows ($P < .01$). Multivariate analysis of variance demonstrated no significant differences in nasal cannula prong flow between nasal cannula manufacturers. Repeated measures analysis of variance demonstrated significant differences for measured inspired F_{IO_2} ($P < .01$) when alternating nares were occluded and patent. The Bonferroni post hoc test showed significant differences for measured F_{IO_2} between patent nares and right naris patent-left naris occluded ($P < .01$) and between patent nares and left naris patent-right naris occluded ($P < .01$). Measured F_{IO_2} decreased by as much as 0.1 when one naris was occluded. CONCLUSIONS: Oxygen delivery by nasal cannula may be inefficient in the presence of the nasal cycle. Delivered nasal cannula oxygen concentrations decreased when bilateral nasal patency changed to unilateral nasal patency. Although statistically different, nasal cannula prong oxygen flow may not be clinically important across the full range of flows. *Key words: nasal cannula; nasal cycle; nasal cannula prong; nasal airflow; nasal resistance.* [Respir Care 0;0(0):1–•. © 0 Daedalus Enterprises]

Introduction

The nose is separated anatomically into 2 independent airways, each containing separate blood vessels and nervous innervation.[1] The phenomenon known as the "nasal cycle" was first reported in scientific literature over 100 y ago and was described by Kayser[2] in 1895. Eccles later described the nasal cycle as "spontaneous and often reciprocal changes in unilateral air flow associated with congestion and decongestion of the nasal venous sinuses."[1]

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This has been reported to cause asymmetrical air flow through the nasal passages with the dominant flow regularly alternating between nasal passages while maintaining a constant total nasal resistance.[3,4] Heetderks[5] reported that the duration of each nasal cycle for humans is between 25 min and 4 h with an average of 2.5 h between cycles. Stoksted[6] suggested that nearly 80% of the healthy population appear to exhibit a regular nasal cycle through the day and night.

The variation of air flow through the nasal passages is related to the congestion and decongestion of the nasal venous sinusoids caused by sympathetic adrenergic innervation resulting in vasoconstriction.[3] Keuning[7] hypothesized that the autonomic nervous system probably regulates the nasal cycle via increased parasympathetic activation with loss of sympathetic stimulation of the nostril, resulting in the engorgement of mucous membranes with blood. Eccles and Lee[8] found that stimulation of the hypothalamus in cats caused nasal vasoconstriction, resulting in an increase of the nasal airway lumen. More recent studies by Flanagan and Eccles[9] have attempted to quantify air flow changes between the nasal passages over time. Although the cause and effect of nasal cycling remains something of a mystery today, nasal cycling has been shown to be present in infants, children, adults, and the majority of mammals, such as rats, rabbits, domestic pigs, cats, and dogs, with synchronous changes in electrocortical activity reported with each cycling.[3,10] Changes in posture and body positioning have also been shown to influence nasal cycling with dependent tissues becoming engorged.[11]

Ideally, the left and right sides of the nose would have identical cycling periods that are phased oppositely, resulting in a similar mean air flow, amplitude, resistance, and volume. For most individuals, the sensation of nasal cycling is not recognized as long as normal nasal anatomy is present.[4] However, for some individuals, this is not the case because there can be wide variations in air flow dynamics with the duration of cycling ranging from 30 min to 6 h.[3,12] The presence of an upper respiratory infection has been shown to increase the unilateral nasal resistance associated with the nasal cycle and has the ability to completely occlude a nasal passage.[3] Although the actual purpose of nasal cycling is not known, the event has been attributed to enhancing humidification and mucociliary clearance during the congested phase and assisting in the defense against respiratory infection.[3,13] Eccles[3] suggests that the nasal cycle may be linked to the formation of nasal secretions by an active pumping mechanism. Following congestion, sympathetic stimulation will cause smooth muscle of the venous sinusoids to contract thereby increasing hydrostatic pressure.[3] This results in a leakage of plasma exudate from the endothelium and contribution to the respiratory defense of microorganisms by providing plasma immunoglobins to the epithelial cells of the nasal mucosa.[3,4]

QUICK LOOK

Current knowledge

The nose is separated anatomically into 2 independent passages, and the phenomenon known as nasal cycling is the spontaneous change in unilateral airflow as a result of congestion and decongestion of the right or left nasal venous sinuses. The vast majority of the healthy population exhibit regular nasal cycling through the day and night. The nasal cannula is one of the most common oxygen delivery adjuncts used to deliver supplemental oxygen. The right and left prong of the nasal cannula is designed to deliver oxygen to its respective naris. There are no previous studies comparing right and left prong oxygen flow for nasal cannula adjuncts at various therapeutic flow settings.

What this paper contributes to our knowledge

A comparison of 5 brands of nasal cannulas measuring right and left nasal cannula prong flows showed statistically significant differences between right and left prong delivery for some flows. The anatomically correct adult head model used to evaluate F_{IO_2} delivery for occluded and unoccluded simulated nasal cycling conditions showed differences in delivered oxygen concentration in the presence of unilateral oxygen delivery due to changes in nasal patency. Differences in delivered F_{IO_2} during simulated anatomical nasal cycling events were more pronounced in flows >2 L/min.

The nasal cannula is one of the most common oxygen delivery adjuncts used when delivering supplemental oxygen.[14] The nasal cannula is a plastic, disposable, low-flow device used to deliver up to 6 L/min of oxygen.[15] It consists of 7 or 14 feet of crush-resistant small bore oxygen tubing and 2 prongs that are approximately 1 cm in length, which are placed directly into the patient's nares.[15] Previous literature has demonstrated a large variation of measured F_{IO_2} when delivering oxygen by nasal cannula using different sampling techniques.[16-18] Due to this, Ward[14] stated that measured F_{IO_2} delivered by nasal cannula is not clinically practical, and the stated F_{IO_2} listed in textbooks is overstated. Limitations of low-flow nasal cannulas include the entrainment of room air when a patient breathes because the nasal cannula fails to provide enough flow to meet the patient's inspiratory demand, and the delivered flow to the patient is affected by the patient's flow pattern, such as the spontaneous inspiratory and expiratory ratio and the patient's nasal, nasopharynx, and oropharynx anatomy.[14]

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Acknowledging nasal cycling as a persistent physiological event throughout the day and night while keeping in mind the large population of individuals using a nasal cannula for oxygen therapy, the primary aim of this bench study is to evaluate the effects of nasal cycling on the delivered F_{IO_2} during oxygen administration via nasal cannula at various therapeutic flows to an anatomic model. Additionally, a thorough review of the literature revealed no previous studies comparing right and left prong oxygen flow for nasal cannula adjuncts at various therapeutic flow settings. We first sought to determine whether significant differences existed between right and left prong flow and then evaluated the effects of nasal cycling on the F_{IO_2} delivered via nasal cannula. The null hypotheses state: (1) there is no significant difference in the oxygen flow delivered from the right and left nasal cannula prongs, and (2) there is no statistical difference in the inspired F_{IO_2} while using a nasal cannula in the presence of nasal cycling causing complete occlusion of one nasal passage or with patent nasal passages.

Methods

This bench institutional review board-exempt study was performed in 2 phases as a way to answer both research questions. The first phase of data collection was designed to compare the right and left prong oxygen flow for a nasal cannula at a variety of therapeutic settings. Five nasal cannulas from different manufacturers were collected and labeled after opening the packaging to ensure proper identification of each nasal cannula. The studied nasal cannulas were Westmed part 0556 (Tucson, Arizona), Salter Labs part 1600 (Arvin, California), Care Fusion part 002600 (Yorba Linda, California), Hudson RCI part 1820 (Teleflex Medical, Research Triangle Park, North Carolina), and MEDLINE part HCS4511B (MEDLINE Industries, Mundelein, Illinois). Each nasal cannula had 7 feet of crush resistant supply tubing. A back pressure compensated Thorpe-tube style flow meter (Precision Medical, Northampton, Pennsylvania) was used to deliver oxygen flow of 0.5–6 L/min in 0.5-L/min increments. Following the setting of each oxygen flow, a factory-calibrated TSI 4100 thermal mass flow meter (TSI, Shoreview, Minnesota) was used to verify that the Thorpe tube flow meter was delivering the desired flow.

Following Thorpe tube flow verification, each nasal cannula was connected to the flow meter, and 2 thermal mass flow meters were connected to the nasal cannula prongs simultaneously to record the oxygen flow from each nasal cannula prong independently. Measurements were recorded following a 5-min flow stabilization period. Measurements of nasal cannula prong flow were obtained for all 5 nasal cannula brands at the same delivered oxygen flow before making the 0.5-L/min incremental increase. Measurements were recorded for a total of 12 different flows.

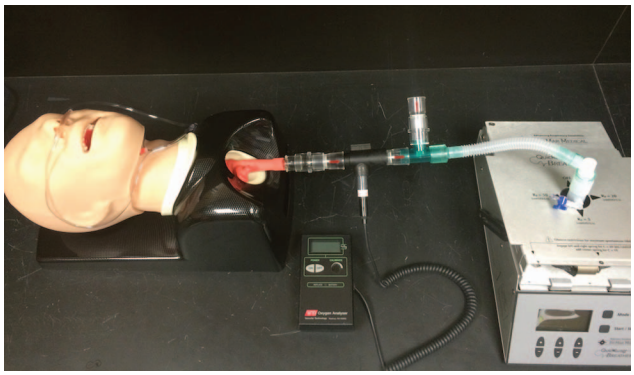

Fig. 1. Adult model with test lung and polarographic oxygen analyzer.

The second phase of data collection was designed to evaluate the effects of nasal cycling on the delivered F_{IO_2} during oxygen administration via a nasal cannula at various therapeutic flows. An adult model was established using the AirSim Advance (TruCorp, Belfast, United Kingdom) mannikin head connected to a QuickLung breather (IngMar Medical, Pittsburgh, Pennsylvania) test lung. The mannikin head utilized for the study was chosen because it has an anatomically accurate upper airway, including nasal turbinates, and was modeled using computed tomography data from an adult male.[19] This model would allow the mixing of inspired gas in the nasopharynx similar to normal physiology. The test lung was set to eupnea with a tidal volume of 500 mL, frequency of 15, and I-E ratio of 1:2 to simulate normal resting ventilation. Exhaled tidal volumes were verified with a Wright respirometer (Ferraris Medical, London, United Kingdom). A polarographic oxygen analyzer (Vascular Technology, Nashua, New Hampshire) was placed inline between the mannikin head and test lung. One-way valves (Hudson RCI, Temecula, California) were placed proximal and distal to the oxygen analyzer T-piece. An aerosol t-adapter (Hudson RCI, Temecula, California) was placed between the distal one-way valve and the test lung. An additional one-way valve was placed on the 90° port of the t-adapter to act as an exhalation valve. The one-way valves allowed accurate F_{IO_2} readings by preventing the analysis of any oxygen reservoir within the system distal to the oxygen analyzer. Figure 1 illustrates the adult model connected to the QuickLung breather test lung. A Salter Labs nasal cannula was placed onto the mannikin head with oxygen delivered at 0.5–6 L/min in 0.5-L/min increments using a back pressure-compensated Thorpe tube style flow meter. Oxygen flow from the flow meter was verified using a thermal mass flow meter. As originally designed by the manufacturer, the mouth of the mannikin was left open to the atmosphere during data collection. The inspired F_{IO_2} was

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Table 1. Mean Oxygen Flow and SD for the Nasal Cannula Prongs at Each Delivered Oxygen Flow

Oxygen Flow, L/min	Right Prong, mean ± SD L/min*	Left Prong, mean ± SD L/min*
0.5	0.26 ± 0.03	0.2 ± 0.02
1	0.52 ± 0.03	0.43 ± 0.02
1.5	0.75 ± 0.03	0.64 ± 0.02
2	1 ± 0.09	0.89 ± 0.12
2.5	1.22 ± 0.08	1.11 ± 0.08
3	1.47 ± 0.11	1.36 ± 0.08
3.5	1.71 ± 0.19	1.62 ± 0.19
4	1.99 ± 0.08	1.93 ± 0.1
4.5	2.14 ± 0.12	1.88 ± 0.18
5	2.5 ± 0.2	2.70 ± 0.18
5.5	2.67 ± 0.15	2.65 ± 0.22
6	2.89 ± 0.09	2.85 ± 0.21

* $P < .01$, right nasal cannula prong vs left nasal cannula prong.

measured using the polarographic oxygen analyzer with mannikin nares patent, the right naris occluded, and then the left naris occluded, sequentially. Advancing a size 5.0 endotracheal tube (Teleflex Medical, Research Triangle Park, North Carolina) 8 cm into the nasal cavity and inflation of the endotracheal tube cuff simulated complete naris occlusion. The endotracheal tube 15-mm connector was occluded and sealed with plumbers' putty to prevent additional entrainment of ambient air through the endotracheal tube.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics 20 (IBM, Armonk, New York). The data for nasal cannula prong flows were analyzed using the paired *t* test and the multivariate analysis of variance statistical method at an α level of 0.05. The data for nasal cycling when using the adult model were analyzed using the repeated measures analysis of variance and Bonferroni post hoc statistical methods at an α level of 0.05.

Results

Table 1 displays the mean oxygen flow and SD values for right and left nasal cannula prong at each delivered flow when evaluating flow through each nasal cannula prong independently. The paired *t* test demonstrated a significant difference between the oxygen flow from the right and left nasal cannula prongs with a *P* value of $< .01$. Table 2 displays the measured flow by nasal cannula prong for each studied nasal cannula at all studied oxygen flows. The multivariate analysis of variance statistical method did not demonstrate a significant difference when comparing the right nasal cannula prongs among all studied nasal cannulas and when comparing the left nasal cannula prongs among all studied nasal cannula with a *P* value of .67.

Table 3 displays the calculated and measured F_{IO_2} when using the adult model for each measured flow and naris patency. The repeated measures analysis of variance demonstrated a significant difference in measured oxygen percentage with $P < .01$. The Bonferroni post hoc statistical method demonstrated significant differences between patent nares (measured oxygen percentage) and the left naris occluded, with $P < .01$, and between patent nares (measured oxygen percentage) and the right naris occluded, with $P < .01$.

Discussion

Oxygen therapy is recognized as an important component of the management and survival of patients with hypoxemia, and the nasal cannula is the most commonly prescribed delivery adjunct.[20-22] The association between the nasal cycle and oxygen delivery via nasal cannula has received very little attention in the available literature. The primary aim of this bench study was to evaluate the effects of simulated nasal cycling on the delivered F_{IO_2} during oxygen administration via nasal cannula.

Initially, a comparison of the oxygen flow between the right and left nasal prong required investigation. Five brands of nasal cannulas were evaluated to determine whether a difference between right and left nasal cannula prong flows existed. The gas flow exiting each nasal cannula prong represents roughly half of the flow meter setting (Tables 1 and 2). There was a statistically significant difference between the mean values for the right and left prong, with right prong flow exceeding left prong flow, when considering all of the nasal cannulas (Table 1). As a result of these findings, the first null hypothesis stating that there is no significant difference in the oxygen flow delivered from the right and left nasal cannula prongs was rejected. The data did not reach statistical significance when comparing the right prong flows among all studied nasal cannulas and did not reach statistical significance when comparing left prong flows among all studied nasal cannulas (Table 2). Both tables provide insight into gas delivery through adult nasal cannula prongs. When examining nasal cannula by brand, the results suggest that any of the 5 cannulas will provide the same flow characteristics through the right and left prongs. However, there were observable differences between prong flows. The right prong provided a higher flow than the left prong for most of the flows used among all nasal cannula brands. In addition to providing the foundation for the second phase of this study, the data in Tables 1 and 2 allows us to theorize on the clinical impact. When both nares are patent, the expectation is that right plus left prong flow will eventually combine in the nasopharyngeal

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Table 2. Measured Flows for Each Nasal Cannula Prong at Each Delivered Oxygen Flow

Flow L/min	Measured Oxygen Flow L/min*									
	Westmed		Salter Labs		Care Fusion		Hudson RCI		Medline	
	Right Prong	Left Prong	Right Prong	Left Prong	Right Prong	Left Prong	Right Prong	Left Prong	Right Prong	Left Prong
0.5	0.254	0.205	0.274	0.217	0.269	0.214	0.211	0.161	0.271	0.216
1	0.476	0.396	0.551	0.442	0.523	0.432	0.522	0.418	0.546	0.442
1.5	0.716	0.623	0.782	0.662	0.765	0.66	0.711	0.61	0.768	0.659
2	1.058	0.928	1.05	0.96	1.04	0.92	0.852	0.672	1.048	0.951
2.5	1.15	1.075	1.318	1.195	1.248	1.158	1.164	1.031	1.281	1.199
3	1.455	1.383	1.571	1.418	1.432	1.371	1.543	1.371	1.534	1.423
3.5	1.754	1.676	1.806	1.718	1.820	1.699	1.37	1.274	1.785	1.724
4	2.005	1.95	2.053	1.966	2.048	1.966	1.844	1.746	1.988	2.007
4.5	2.094	1.869	2.289	2.066	2.051	1.793	2.014	1.638	2.24	2.051
5	2.224	2.54	2.702	2.889	2.571	2.733	2.364	2.484	2.653	2.859
5.5	2.683	2.613	2.857	2.654	2.75	2.659	2.453	2.362	2.629	2.984
6	2.75	2.866	2.941	3.035	2.926	2.923	2.859	2.49	2.986	2.941

* P = .67, right nasal cannula prongs compared between all studied nasal cannulas and left nasal cannula prongs compared between all studied nasal cannulas.

Table 3. Expected and Observed Delivered Oxygen Percentage for Each Measured Flow and Nares Patency

Oxygen Flow, L/min	Patent Nares, Measured Oxygen %	Left Naris Occluded, Measured Oxygen %*	Right Naris Occluded, Measured Oxygen %†
0.5	24.7	24.3	24.9
1	27.7	27.2	27.2
1.5	30.4	29.5	29.5
2	33.8	30.5	31.6
2.5	36.1	31.9	33.6
3	38	34.3	35.4
3.5	40.4	34.6	35.3
4	40.7	35.4	36.7
4.5	44.2	35.8	39.3
5	45.1	35.8	39.8
5.5	47.3	36.4	40.5
6	48.3	38.1	42.1

* $P < .01$, patent (measured) vs left naris occluded.
† $P < .01$, patent (measured) vs right naris occluded.

cavity. In this scenario, the difference between right and left prong flow is insignificant. However, it is plausible that the manifestation of nasal cycling in the presence of the cannula prong flows reported above (ie, about half the total flow travels through each prong) could impact oxygen delivery. Additionally, the differences observed between right and left prong flow could create a greater or lesser change in oxygen delivery when nasal cycling is occurring. Once again, the data in Tables 1 and 2 show that right prong flow is consistently greater than left prong flow.

The second phase of this project assessed F_{IO_2} delivery to the lower airway, as a surrogate of gas delivery, in an adult mannikin when right or left nares were occluded to simulate nasal cycling. Our F_{IO_2} results (Table 3) for each nasal cannula flow are consistent with other studies in the available literature. We saw increases in F_{IO_2} with incremental increases in oxygen flow. This finding occurred whether both nares were patent or one of the nares was occluded.

The novel findings within this study relate to the F_{IO_2} changes when unilateral nasal occlusion occurred. Our results demonstrate that a simulated nasal cycle can impact delivered F_{IO_2} distal to the delivery device. Table 3 communicates the differences in delivered oxygen concentration with patent right and left nares versus a unilateral occlusion. Multiple times a decrease in the delivered F_{IO_2} by as much as 10% was noted, resulting in a 21% change when comparing the measured F_{IO_2} associated with patent nares and the measured F_{IO_2} associated with individual naris occlusion. Due to these findings, the second null hypothesis stating that there is no statistical difference in the inspired F_{IO_2} while using a nasal cannula in the presence of nasal cycling causing complete occlusion of one nasal passage or with patent nasal passages was rejected. Interestingly, the differences in delivered F_{IO_2} were not as great with flows <2 L/min.

Collectively, these findings have important implications for patients using oxygen therapy via nasal cannula. First, the data indicate that delivered oxygen concentrations decrease when bilateral nasal patency changes to unilateral patency. It is recognized that adjustment in oxygen flow is a consideration based on certain circumstances (eg, sleeping, awake, and with exercise).[23] Other variables necessi-

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tating an adjustment in oxygen flow include patient tidal volume, nasopharyngeal volume, the delivery mechanism (eg, continuous flow or intermittent flow/pulsed flow), the patient's breathing frequency, and the inspiratory time.[24] The human nasal cycle may be another factor to consider when delivering oxygen via nasal cannula. The human nasal cycle appears to run on a schedule unrelated to activity and sleeping/waking schedules; therefore, adjustment in oxygen flow would need to occur based on physiological feedback from the patient. Adjusting oxygen flows to accommodate the physiological nasal cycle adds another factor to be considered in the management of patients requiring low-flow oxygen therapy. If the normal nasal cycle can vary F_{IO_2} delivery by as much as 0.1 in a human, as we demonstrated with a bench model, then oxygen flows may need to be adjusted to maintain oxygen saturations and delivery prescriptions. However, adjustment of total flow into the nasal cannula seems less ideal versus adjustment in flow out of each nasal cannula prong. Adjustment of oxygen delivery based on physiologic variables (eg, saturation via pulse oximetry) is not a new idea but appears to be infrequently used.[24] Our results showed that a nasal cannula set at 3 L/min delivered 38% oxygen when the nares were patent. When we simulated nasal cycling, the 3 L/min setting delivered 34.3% with the left naris occluded (Table 3). As a reminder, each prong is delivering roughly half of the total flow (eg, 1.47 ± 0.11) (Table 1). When the total flow was set to 6 L/min and the left naris was occluded, the measured oxygen was 38.1%. Again, the oxygen flow through the right prong is roughly half of the total flow. In this scenario, 3 L/min of oxygen achieved 38% oxygen delivery when both nares were patent and when the full 3 L/min was directed through the right prong only. Therefore, theoretically, adjusting gas flow delivery through right and/or left prongs based on the human nasal cycle could promote a more consistent oxygen delivery percentage.

Second, oxygen delivery by nasal cannula may be an inefficient oxygen delivery device for patients with nasal anatomic abnormalities that would promote unilateral nasal air flow. These anatomic abnormalities could include any pathology that narrows or completely occludes the nasal passage, preventing air flow, such as nasal polyps and deviated septum. Eccles[3] stated that total naris occlusion due to the nasal cycle may occur in the presence of nasal infection. Nasal anatomic abnormalities would cause a decrease in inspired F_{IO_2} similar to nasal cycling due to obstructing oxygen from reaching the nasopharynx from one of the nasal cannula prongs. With current nasal cannulas, a higher oxygen flow may be required to treat hypoxemia in patients with nasal anatomic abnormalities due to the obstruction and/or waste of oxygen.

Third, there is an economic consideration attached to our findings. Once again, we must assume the nasal cycle is a real human phenomenon occurring as previous authors have suggested. If only one naris is patent and able to accept gas delivery through the nasal cannula prong, the other naris is blocked to the flow of gas. As a result, a portion of the prescribed oxygen is probably delivered to the external environment and wasted. This scenario could impact any patient receiving oxygen by nasal cannula, but it is the long-term oxygen therapy (LTOT) patient who carries a larger economic burden of wasted oxygen. Croxton et al[25] published the results of a National Heart, Lung, and Blood Institute (NHLBI) Workshop on LTOT. The NHLBI working group reported that approximately 1 million patients receive LTOT through the Medicare program with reimbursements for oxygen exceeding $2 billion/y.[25] The working group also reported that reimbursements for oxygen were increasing by 12–13%/y.[25] In our model, we can assume that nearly half of the oxygen delivered from the flow meter was not delivered to the lower airway. Given this same scenario for the LTOT patient, it seems reasonable to conclude that an undetermined amount of oxygen and health-care dollars are actually providing incomplete benefits. There are a variety of different ways that oxygen can be wasted into the external environment when using a nasal cannula.[24] This is the first publication to address nasal cycling as a source of oxygen delivery waste.

As a way to reduce the costs associated with the delivery and cost of oxygen therapy, numerous oxygen-conserving devices are available to patients with long-term oxygen needs. In addition, there is a wealth of literature on oxygen-conserving devices and their usefulness in patients requiring oxygen therapy outside of the hospital. Although we do not have complete knowledge on all oxygen-conserving technologies available to patients in the United States and abroad, to our knowledge, there is no conserving device on the market that compensates for nasal cycling and unilateral oxygen delivery through a standard nasal cannula. Although current oxygen-conserving devices reduce the amount of oxygen wastage, none on the market deal with the issue of nasal cycling. Whether the cost of incorporating technology that accounts for nasal cycling into conserving devices is economical or not is outside of the scope of this study, but this is a possible new area for potential cost savings. These devices can provide sophisticated technology to manage oxygen delivery and patient comfort as well as improving the patient's quality of life by improving mobility and range from the home. However, the cost of the technology may be prohibitive compared with the savings in oxygen.

The presence of the nasal cycle may impact the performance of CO_2-sampling nasal cannulas. There are currently 3 varieties of CO_2-sampling nasal cannulas, which consist of nasal cannulas that deliver oxygen through one prong and sample CO_2 through the other prong, nasal can-

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nulas that both deliver oxygen and sample CO_2 through the nasal prongs, and nasal cannulas that deliver oxygen by producing an oxygen cloud around the nares and sampling CO_2 through the nasal cannula prongs.[26] When using the CO_2-sampling nasal cannula that delivers oxygen through one prong and samples CO_2 through the opposite prong, a potential decrease in delivered oxygen to the nasal cavity may occur when complete or partial occlusion of the nasal cavity occurs on the same side of oxygen delivery by the CO_2 sampling nasal cannula. Additionally, erroneous measurements of monitored CO_2 may occur when partial or complete obstruction of the nasal cavity occurs on the same side of the CO_2 sampling prong. Further research should be performed evaluating the effectiveness of CO_2 sampling nasal cannulas with the presence of nasal cycling.

There were some limitations to this study. We used a mannikin head to gather our data, and, undoubtedly, a human head will have different response characteristics. Since we only gathered data using an adult head mannikin, we cannot generalize our findings to a neonatal or pediatric mannikin model or a neonatal and pediatric human. We created a complete occlusion when simulating nasal cycling. It is possible that in a human subject, the nasal cycling phenomenon may represent a partial or incomplete occlusion. Therefore, the results will be different from person to person depending on anatomic structures and degree of occlusion. We used F_{IO_2} measurements instead of flow measurements as a way to demonstrate oxygen delivery to the distal airway of our adult mannikin model. We used a continuous oxygen delivery setup for the experiments. We did not test the effects of nasal cycling on oxygen-conserving equipment. We used settings to mimic a resting ventilation pattern and did not simulate tachypnea. Further research studying the effects of nasal cycling during tachypnea would be beneficial. Furthermore, the adult model used a one-way valve approach, creating unilateral flow in the simulated trachea instead of the in vivo to-and-fro physiological breathing pattern. This may account for the higher F_{IO_2} observed in this study when compared with previous studies measuring F_{IO_2} collected on subjects wearing nasal cannulas.[16-18]

Conclusions

Evaluating the flow of oxygen from nasal cannula prongs comparing 5 brands of nasal cannula devices revealed a statistically significant difference between right and left nasal cannula prong flow; however, the difference may not be clinically important. Delivering oxygen by nasal cannula during nasal cycling, causing a completely obstructed naris, may lead to a diminished F_{IO_2} and may be insufficient for patient oxygen demands. Traditional nasal cannula usage in the presence of the human nasal cycle may result in oxygen waste for patients receiving LTOT and a failure to deliver the prescribed amount of oxygen to the patient. Because of this, clinicians should consider the effects of nasal cycling when delivering low-flow oxygen by nasal cannula.

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