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A M E R I C A N C O L L E G E O F



P H Y S I C I A N S[®]

Conservation of Oxygen Supply Using a Reservoir Nasal Cannula in Hypoxemic Patients at Rest and during Exercise*

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A reservoir nasal cannula which stores oxygen during exhalation and delivers it as a bolus during inhalation has been reported to conserve oxygen delivery in patients with chronic obstructive pulmonary disease (COPD) at rest. We compared the effects upon arterial oxygen saturation (SaO_2) of the reservoir cannula and a standard nasal cannula in hypoxemic obstructed and restricted patients at rest and during exercise. The SaO_2 was monitored by ear oximeter. While at rest, 13 obstructed and four restricted patients breathed oxygen from the reservoir cannula at 0.5, 1.0, 1.5, and 2.0 L/min and from a standard cannula at 0.5, 1.0, 2.0, 3.0, and 4.0 L/min. Mean SaO_2 was significantly higher with the reservoir cannula compared to the standard cannula at 1.0 and 2.0 L/min ($p < 0.0006$) and tended to be higher at 0.5 L/min ($p < 0.1$). Seven obstructed patients walked on a level

treadmill at 0.75 mph while breathing oxygen at 0.5 and 1.5 L/min from the reservoir cannula and at 1.0 and 3.0 L/min from the standard cannula. The SaO_2 during exercise with the reservoir cannula was comparable to that with the standard cannula at approximately half of the oxygen flow rate. The ratio of the oxygen flow rate of the standard to the reservoir cannula to produce 90 percent saturation was estimated and found to be 2.5 ± 0.8 (mean \pm SD) for patients at rest and 2.9 ± 1.8 during exercise. We conclude that in hypoxemic patients at rest and during exercise, the reservoir cannula uses less than half the oxygen of a standard cannula to produce similar improvement in SaO_2 , and thus has advantages of a reduced cost of ambulatory therapy with low-flow oxygen and a longer time permitted away from a stationary source of oxygen.

Because supplemental oxygen improves survival in hypoxemic patients with chronic obstructive pulmonary disease (COPD) and presumably in patients with chronic restrictive disease, delivery of oxygen to the hypoxemic patient by nasal cannula is an established mode of therapy. Despite the acknowledged efficacy, there is concern regarding the cost of this treatment. Moreover, the limited duration of oxygen supply from portable sources poses an inconvenience to ambulatory patients.

Delivery of oxygen by nasal cannula is inherently inefficient due to the oxygen escaping into the atmosphere during exhalation. Several devices are in development or are being marketed to improve the oxygen efficiency of the nasal cannula. In this study, we tested a widely marketed, simple-to-operate example of these devices, a nasal cannula with a built-in reservoir

(Oxymizer, Chad Therapeutics, Inc). This cannula stores oxygen during exhalation, delivering the stored oxygen as a bolus during inhalation.¹ We tested this device in patients with hypoxemic pulmonary disease at rest and with ambulation to determine its efficiency and oxygen-conserving ability compared with the standard nasal cannula.

MATERIALS AND METHODS

Twenty subjects were selected from patients cared for in the Pulmonary Divisions of the UCLA Medical Center, Los Angeles, and the Veterans Administration Hospital, Sepulveda, Calif. Subjects were selected for study if they had stable chronic obstructive or restrictive ventilatory disease and were already receiving long-term therapy with low-flow oxygen or were being evaluated for the first time for supplemental oxygen therapy at home. Subjects were further screened for inclusion in the study by ear oximeter (Biox Technology model II-A). The criterion for selection was arterial oxygen saturation (SaO_2) of 90 percent or less while breathing room air. Subjects signed an informed consent approved by the human subjects' protection committee at the institution where the study was performed.

All subjects underwent routine spirometric testing using a rolling-seal spirometer (Cardio-Pulmonary Instruments model 220) and measurement of arterial blood gas levels. Determination of blood gas levels was in duplicate using a semiautomated blood gas analyzer (Corning Medical model 168). The SaO_2 and carboxyhemoglobin saturation of arterial blood were determined with a spectrophotometric oximeter (CO-Oximeter model IL287; Instrumentation Laboratory, Inc). Wherever possible, arterial blood was sampled simultaneously with an ear oximeter. Subjects then underwent studies with a nasal cannula as described subsequently.

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Each subject was studied at rest with both a standard nasal cannula (Salter Labs model 1600) and a reservoir nasal cannula applied in random order. An ear oximeter was used to monitor arterial oxyhemoglobin saturation while air at 1.0 L/min and oxygen at 0.5 (in only four obstructed and three restricted subjects), 1.0, 2.0, 3.0, and 4.0 L/min were delivered to the standard nasal cannula or air at 1.0 L/min and oxygen at 0.5, 1.0, 1.5, and 2.0 L/min were delivered to the reservoir cannula. The patients breathed oxygen at each flow rate for at least five minutes, and arterial saturation was recorded after it had achieved a stable value for an additional two minutes. When all measurements were completed with one type of cannula, the procedure was repeated with the other type of cannula, starting with air and followed by the breathing of oxygen at the flow rates in the sequence indicated previously. Subjects were observed continuously to monitor respiratory rate and to ascertain whether breathing was through the nose, mouth, or both. The respiratory rate and predominant mode of breathing were recorded for each oxygen flow rate tested.

The seven obstructed patients studied at the UCLA Medical Center were selected to determine if the reservoir cannula would conserve oxygen during exercise. The subjects were screened by ear oximeter while walking to ensure that their SaO₂ on room air remained at 90 percent or less with exercise. These subjects were studied during exercise while breathing supplemental oxygen at 0.5 and 1.5 L/min via the reservoir cannula and at 1 and 3 L/min via the standard cannula. The studies were carried out at the same session as the resting protocol, which was modified in the following way. After subjects had reached a steady state at rest breathing oxygen at 0.5 or 1.5 L/min via the reservoir nasal cannula and at 1 and 3 L/min via the standard nasal cannula, they walked on a level treadmill at 0.75 mph for a target duration of five minutes while continuing to inspire supplemental oxygen at the same flow rate via the same cannula that they used during the preceding resting period. Two subjects were unable to walk for the full five minutes but walked for at least three minutes during all exercise periods. Respiratory frequency was counted, and the pattern of breathing (nose, mouth, or both) was noted during the last 30 seconds of exercise. Following each exercise period, subjects were switched to the next higher flow rate of oxygen indicated by the resting protocol and rested (generally for more than ten minutes) until a new steady level of SaO₂ was achieved.

Statistical analyses were performed separately in subjects with obstructive and restrictive ventilatory impairment. A two-way analysis of variance by subject and type of cannula was used to determine if significant differences existed in each group of subjects between the SaO₂ achieved with the two types of nasal cannulae delivering the same flow rate of oxygen.

A similar analysis was used to determine if SaO₂ at twice the oxygen flow rate with the standard cannula was different compared to the reservoir cannula. An oxygen conservation ratio at 90 percent saturation and the percentage of savings in oxygen supply required to achieve 90 percent saturation were calculated to quantitatively estimate the oxygen-sparing capabilities of the reservoir cannula compared to the standard cannula. The conservation ratio at 90 percent saturation was defined as the flow rate for the standard cannula divided by the flow rate for the reservoir-type cannula required to achieve 90 percent saturation. The flow rate of oxygen required to achieve an SaO₂ of 90 percent was estimated for each type of cannula by linear interpolation of the data. The method of calculating the conservation ratio for subject 4 with COPD is shown in Figure 1. The percentage of savings in oxygen supply was determined by subtracting the reciprocal of the concentration ratio from one and multiplying by 100. Student's *t*-test was used to determine the significance of the difference in the percent savings in oxygen supply from zero. Least-squares linear regression was used for all subjects combined to test the correlation between arterial saturation measured by ear oximeter and spectrophotometric oximeter and the correlation between conservation ratio or percentage of savings in oxygen supply and respiratory rate.

RESULTS

Table 1 lists the subjects' baseline characteristics. Oxyhemoglobin and carboxyhemoglobin saturations by spectrophotometric oximeter were not obtained in subjects 4 and 11. Subjects 1, 3, and 18 to 20 had an SaO₂ of 90 percent or less at the time of screening but were later found to have an SaO₂ of more than 90 percent by oximeter on the day of the study. Subjects 1 and 3 with SaO₂ above 90 percent by ear oximeter had spectrophotometric oximetric data indicating an SaO₂ of 90 percent or less. These subjects were included in the resting studies. Subjects 18 to 20 were studied during exercise but not at rest because they had sufficient desaturation only during exercise to meet the criterion of an SaO₂ of 90 percent or less on room air. Four patients had carboxyhemoglobin values that were significantly elevated, presumably due to cigarette smoking prior to the study. The mean intraindividual difference between SaO₂ determined by ear oximeter and the spectrophotometric oximeter (0.5 ± 2.6 percent) was not significantly different from zero. Linear

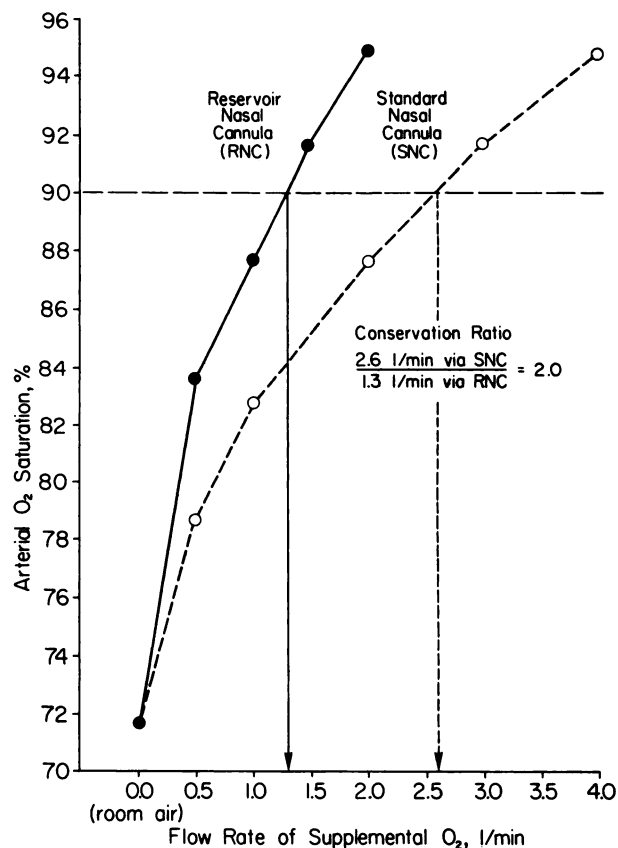


FIGURE 1. Method of calculating oxygen conservation ratio. Ear oximetric SaO₂ was determined at indicated oxygen flow rates through reservoir nasal cannula and standard nasal cannula. Oxygen flow rate to produce 90 percent saturation is determined by linear interpolation between two oxygen flow rates that most closely bracket 90 percent saturation. Oxygen conservation ratio is then calculated by dividing oxygen flow rate of standard nasal cannula by oxygen flow rate of reservoir cannula corresponding to 90 percent saturation. Oxygen conservation ratio in this obstructed patient is 2.0 (case 4).

Table 1—Data on Pulmonary Function and Blood Gas Levels

Group and Case, Sex, Age (yr)*	Diagnosis†	FVC, L (percent of predicted)	FEV ₁ , L (percent of predicted)	FEV ₁ /FVC, percent	Resting Arterial Blood Gas Levels‡						
					pH	PaCO ₂ , mm Hg	PaO ₂ , mm Hg	SaO ₂ , percent		COHb Saturation, percent	
								Co-Ox	Ear		
Obstructed											
1, F, 69§	COPD	1.66 56	0.86 41	52	7.42	34	71	90	94	6.75¶	
2, M, 66	COPD	3.34 56	1.41 44	42	7.41	43	52	84	86	2.0	
3, M, 29§	CF	2.04 39	1.21 29	59	7.35	59	60	90	91	1.2	
4, F, 49	COPD	1.49 46	0.63 26	42	7.48	45	35	...	73	...	
9, M, 60	COPD	0.87 24	0.31 12	35	7.33	52	50	86	88	1.4	
10, M, 32	CF	1.20 25	0.76 19	63	7.36	56	53	85	90	2.3	
11, M, 61	COPD	1.52 41	0.54 21	35	7.38	61	45	...	84	...	
12, M, 61§	COPD	1.14 31	0.53 21	46	7.39	48	58	87	88	1.3	
13, M, 59	COPD	1.45 36	0.40 14	27	7.45	52	55	89	89	2.1	
14, M, 37§	CF	1.74 31	0.58 13	33	7.34	50	60	88	90	2.1	
15, M, 50	COPD	1.66 43	0.70 25	42	7.44	41	48	85	83	1.2	
16, M, 59	COPD	1.18 33	0.48 19	41	7.32	56	58	84	86	6.1¶	
17, M, 54	COPD	2.55 61	1.45 48	57	7.46	34	54	90	86	1.1	
18, M, 57	COPD	2.10 49	0.79 26	38	7.46	28	68	93	91	2.1	
19, F, 65	COPD	1.11 44	0.52 29	47	7.43	46	68	94	93	1.8	
20, F, 73	COPD	1.91 52	0.55 16	29	7.45	41	66	91	94	4.1¶	
Mean	...	1.69 42	0.73 25	43	7.40	47	56	88	88	2.5	
SD	...	0.62 11	0.34 11	11	0.05	9	9	3	5	1.8	
Restricted											
5, F, 66	IPF	1.26 50	1.18 65	93	7.50	42	36	70	68	1.9	
	Thoraco-										
	plasty	0.76 27	0.60 30	79	7.44	52	51	87	88	2.1	
6, F, 75	IPF	1.17 26	1.03 33	88	7.42	37	51	84	84	1.5	
7, M, 64	IPF	2.05 59	1.57 66	77	7.53	32	57	89	85	5.2¶	
8, M, 62	IPF	2.05 59	1.57 66	77	7.53	32	57	89	85	5.2¶	
Mean	...	1.31 41	1.10 49	84	7.47	41	49	83	81	2.7	
SD	...	0.54 17	0.40 20	8	0.05	9	9	9	9	1.7	

*Mean age of obstructed patients was 55 ± 13 years and of restricted patients was 67 ± 6 years.

†CF, Cystic fibrosis; and IPF, diffuse interstitial pulmonary fibrosis.

‡Co-ox, co-oximeter; ear, ear oximeter; COHb, carboxyhemoglobin; and PaCO₂, arterial carbon dioxide tension.

§Studied both at rest and during exercise.

||Studied only during exercise because resting SaO₂ greater than 90 percent (see text).

¶Elevated COHb values for residents of Los Angeles.

regression for the 18 paired samples analyzed by both types of oximeter yielded a correlation coefficient of 0.90 ($p < 0.001$) and a slope of 1.02. This is in agreement with previously reported results;² however, individual differences were as high as 4.5 percent in patients with elevated carboxyhemoglobin values. Due to these variations, all ear oximetric data were adjusted by simple subtraction to reflect the difference between the ear oximetric and spectrophotometric oximetric values obtained simultaneously at baseline.

Figure 2 shows the mean adjusted resting SaO₂ by ear oximeter for air and supplemental oxygen at each flow rate with each type of cannula for subjects with chronic obstructive and restrictive ventilatory disorders separately. Data are presented only for those 17 subjects with resting SaO₂ of 90 percent or less on room air by spectrophotometric oximeter. Table 2 shows the mean values and range in values for the conservation ratios and percentage of savings in oxygen supply in the obstructed and restricted patients separately.

No differences were noted between the saturations achieved when compressed air was delivered through

either the reservoir or standard cannula ($p > 0.3$). In the obstructed patients, mean saturations were significantly higher with the reservoir cannula than the standard cannula when oxygen was delivered at 1 and 2 L/min ($p < 0.0006$). At an oxygen flow rate of 0.5 L/min administered to four subjects via each type of cannula, a similar trend was noted ($p < 0.1$), which, however, did not achieve statistical significance. When data from all 13 obstructed subjects were analyzed, a significantly higher saturation was noted with 0.5 L/min delivered via the reservoir cannula compared to twice this flow rate delivered by the standard cannula ($p < 0.05$). The values for SaO₂ achieved with oxygen flow rates of 1.0, 1.5, and 2.0 L/min delivered by the reservoir cannula are not significantly different from values for SaO₂ attained with 2, 3, and 4 L/min, respectively, delivered via the standard cannula. The mean individual conservation ratio at an SaO₂ of 90 percent is 2.5 ± 0.8 , corresponding to a mean savings in oxygen supply of 60 ± 17 percent, a value significantly different from zero ($p < 0.0001$).

Although the mean values for SaO₂ were higher with

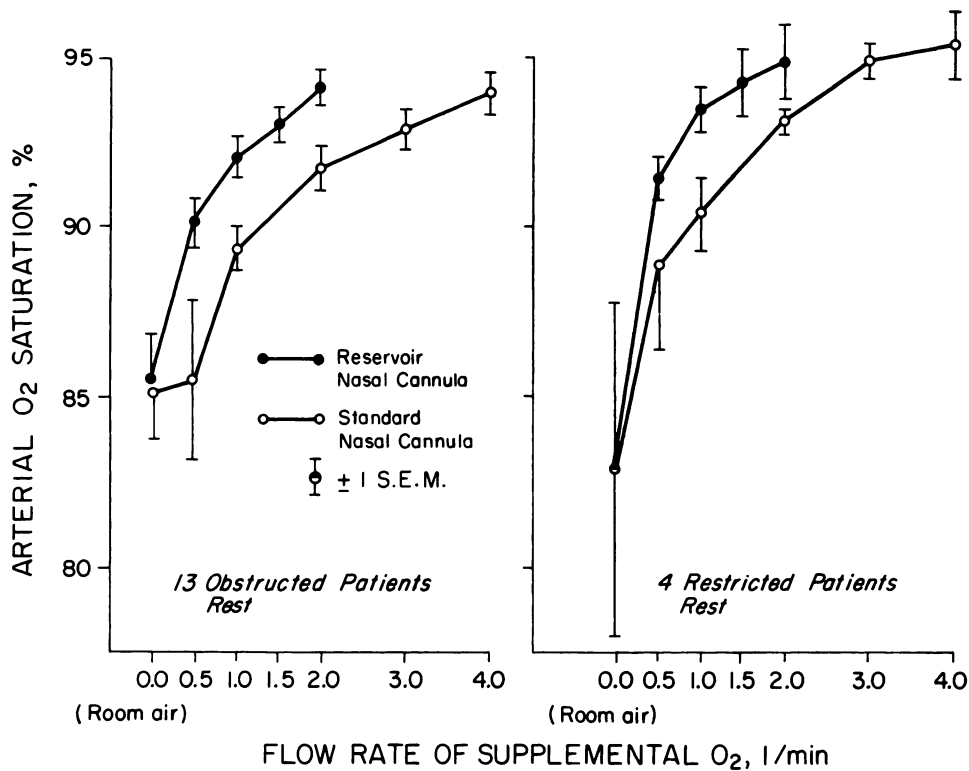


FIGURE 2. Ear oximetric SaO_2 obtained in 13 obstructed and four restricted patients at rest with indicated flow rates of oxygen through reservoir nasal cannula and standard nasal cannula. A flow rate of 0.5 L/min was delivered through the standard cannula in only four obstructed and three restricted patients.

the reservoir than the standard cannula in the four patients with restrictive ventilatory disease when comparable flow rates of oxygen were delivered, these differences were not significantly different by analysis of variance ($p < 0.2$). This is not surprising in view of the small number of such patients studied; however, one of the four restricted patients showed marked oxygen conservation with the reservoir cannula (conservation ratio of 3.5 and oxygen savings of 71 percent).

The oxyhemoglobin saturations observed in the seven patients with obstructive pulmonary disease who exercised breathing room air and oxygen at different flow rates with each type of cannula are shown in Figure 3. The values for SaO_2 achieved with the reservoir cannula at 0.5, 1.0, and 1.5 L/min are comparable to those attained with the standard cannula at twice these oxygen flow rates.

Table 2—Oxygen Conservation Ratios and Percent Savings*

Data	No. of Patients	Conservation Ratio	Percent Oxygen Savings
Obstructed			
Rest	13	2.5 ± 0.8 (1.5-4.0)	$60 \pm 17\uparrow$ (34-75)
Exercise	7	2.9 ± 1.8 (1.1-6.0)	$51 \pm 29\ddagger$ (7-83)
Restricted			
Rest	4	1.6 ± 1.3 (0.8-3.5)	14 ± 40 (-23-71)

*Table values are means \pm SD; numbers within parentheses are ranges.

$\uparrow p < 0.0001$ (Student's *t*-test compared to zero).

$\ddagger p < 0.05$ (Student's *t*-test compared to zero).

ratios at 90 percent during exercise varied from 1.1 to 6.0, with a mean conservation ratio of 2.9 ± 1.8 , corresponding to an oxygen savings of 51 ± 29 percent, which is significantly different from zero ($p < 0.05$).

Most of the patients were observed to inspire nasally at rest. All seven subjects breathed oronasally during

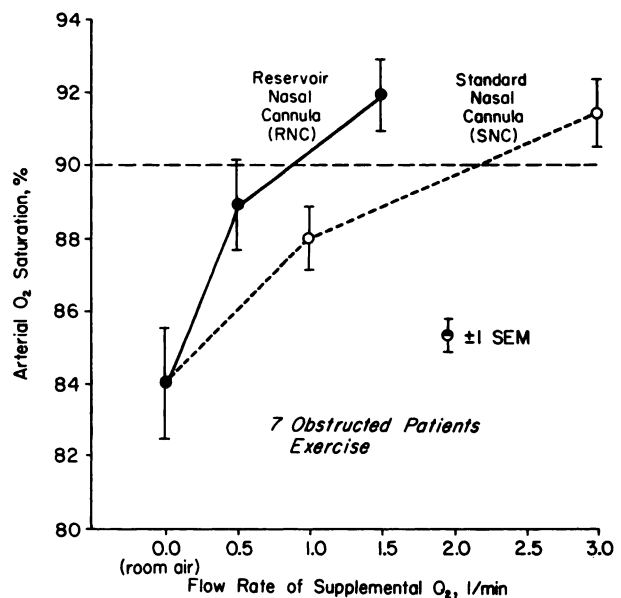


FIGURE 3. Ear oximetric SaO_2 obtained in seven obstructed patients while exercising at 0.75 mph on level grade at indicated oxygen flow rates through reservoir nasal cannula and standard nasal cannula. Dashed line at 90 percent saturation is to aid comparison of oxygen flow rates at that saturation.

exercise. No difference in conservation ratio was noted between the subjects breathing via the nose vs oronasally at rest.

The mean respiratory rate of the obstructed patients at rest while breathing room air was 23 ± 2 breaths per minute and was nearly identical to the respiratory rates observed during oxygen breathing via either cannula at any flow rate. The respiratory rate of the restricted patients during room air breathing was significantly higher (31 ± 3 breaths per minute) than that observed in the obstructed patients ($p < 0.05$). A similar difference in respiratory frequency between the obstructed and restricted patients was also noted during oxygen breathing with either cannula. With exercise the mean respiratory rate of the seven obstructed patients increased significantly ($p < 0.05$) to 28 ± 7 breaths per minute during room-air breathing and did not change significantly while breathing different oxygen concentrations via either cannula. No significant correlation was noted between the conservation ratio or the percentage of oxygen savings and the respiratory rate among all subjects studied either at rest or during exercise ($p > 0.7$).

DISCUSSION

The use of oxygen at 2 L/min continuously by a patient in the Los Angeles area costs about \$400/mo. Over 500,000 persons with advanced COPD are disabled in the United States. If only one in 20 requires ambulatory oxygen, a reduction of oxygen consumption by 50 percent conservatively amounts to \$50,000,000 in annual health-care savings. For the individual patient using 2 L/min continuously, the cost savings even with the additional expense of replacing the reservoir cannula weekly (as recommended by the manufacturers) is \$150/mo if oxygen usage can be reduced to 1 L/min. The reduction of cost at higher oxygen flow rates is even more. For the individual who is able to leave his home with a portable oxygen supply, a 50 percent reduction in flow rate doubles the time one can be away from a stationary supply source of oxygen.

The oxygen-conserving reservoir cannula we have studied is designed to store 20 ml of oxygen flowing from the supply source during the time the patient is exhaling. This reservoir of oxygen is then delivered as a bolus at the beginning of the next breath. This is a very efficient point to deliver the oxygen bolus during the respiratory cycle, since initially inspired gas is distributed to functioning alveoli in most patients. We have shown that this device is capable of producing increases in arterial oxyhemoglobin saturation in hypoxic patients with obstruction equivalent to the increases in saturation produced by the standard nasal cannula at less than half of the oxygen flow rate. With the standard nasal cannula, these patients required 1 to

4 L/min to achieve an SaO_2 of 90 percent at rest. The same results were achieved with the reservoir nasal cannula at flow rates of 0.5 to 2 L/min. The reservoir cannula functioned equally well with the subjects breathing through their nose or through their mouth and nose combined. No conclusion can be drawn about strict mouth breathing, since none of the subjects was a strict mouth breather.

Oxygen saturation in exercising patients frequently decreases below the resting level. Patients requiring low-flow oxygen at rest may need to increase the oxygen flow rate during exercise, and some patients with mild hypoxemia at rest who do not require supplemental oxygen may need oxygen during exercise. The higher flow rates of oxygen via nasal cannula generally required during exercise are due to (1) a lowering of the effective fractional concentration of oxygen in the inspired gas due to the greater dilution of the fixed supplemental flow rate of oxygen by room air during the hyperpnea of exercise, and (2) a tendency for the arterial oxygen tension (PaO_2) in such patients to decrease during exercise due to worsening ventilation-perfusion relationships or diffusion limitation (or both). Because of these differing conditions with exercise, we studied the oxygen-conserving characteristics of the reservoir cannula in seven of our obstructed patients during exercise. In three of these patients, values for SaO_2 were greater than 90 percent at rest. Data for exercise alone are presented for these three patients. As shown in Figure 3, we found that the reservoir cannula resulted in at least as much conservation of oxygen during exercise as we found in the group of 13 obstructed patients studied at rest, despite the greater respiratory frequencies during exercise. These findings indicate that the efficacy of the reservoir cannula is not impaired during the hyperpnea of exercise.

The number of patients with restrictive ventilatory disease in this study did not afford a sufficient sample to draw definite conclusions concerning the utility of the new device for oxygen conservation in this type of patient; however, a marked degree of oxygen conservation (3.5 to 1) was noted in one of the four restricted patients studied. One of the remaining three patients had combined restriction and obstruction. His tidal volume and inspiratory flow rate were so low that the reservoir did not collapse and thus did not deliver a bolus of oxygen. The reservoir acted as a conduit for oxygen, reducing the device to function like the standard cannula in this patient; the oxygen conservation ratio was near one.

The findings in the 13 obstructed patients whom we studied at rest confirm those recently reported by Tjep and colleagues¹ in 20 patients with stable COPD who were evaluated at rest using the same reservoir nasal cannula. Our patients had slightly less obstruction (ratio of the forced expiratory volume in one second

over the forced vital capacity [FEV₁/FVC] of 41.9 ± 11.9 percent; mean \pm SD) than those studied by Tjep et al¹ (FEV₁/FVC of 35.4 ± 4.1 percent), but the level of hypoxemia was slightly greater than in the patients of Tjep et al¹ (85.8 ± 4.5 percent and 88.3 ± 6.8 percent, respectively). We extended the study of oxygen conservation to patients with cystic fibrosis and restrictive disease at rest and obstructed patients during exercise.

Although the reservoir cannula is bulkier and hence less attractive than the standard cannula, this feature did not diminish our patients' interest in this new device for oxygen delivery. Many were anxious to start using the reservoir cannula in an effort to reduce the cost of oxygen therapy and to prolong the duration of time that they could be away from their stationary supply source at home.

Two other oxygen-conserving devices are presently on the market. One (Pendant Oxygen Conserving Cannula; Chad Therapeutics, Inc) is similar in principle to the reservoir cannula tested in this study, except that the reservoir is displaced away from the patient's face.³ This device produces oxygen conservation ratios similar to the device tested in this study. We have had a small number of patients try both devices, and there is no uniformity of preference. The other marketed device is a battery-operated, combination electronic-fluidic device that uses a standard nasal cannula (Demand Oxygen Controller, Cryo-2 Corp). This device regulates oxygen supply so that flow occurs during inspiration and is cut off during expiration. This device decreased usage of supplemental oxygen by 66 percent in 16 patients after surgery.⁴ Comparison of the reservoir cannula and the Demand Oxygen Controller is not possible because the population of patients and the experimental protocols are too dissimilar. Experimental oxygen-conserving devices have been described by Mecikalski and Shigeoka,⁵ by Rinow and Saltzman,⁶ by Crabb et al,⁷ by Anderson et al,⁸ and by others. Additionally, the oxygen-conserving capabilities of percutaneously introduced tracheal catheters, as described by Heimlich,⁹ continue to attract clinical interest.¹⁰

Because of the slightly greater cost and less attractive appearance of the reservoir compared to the standard cannula, it is prudent to document that the reservoir cannula produces significant conservation before prescribing it for any individual patient. If the physician contemplates switching from one type of

oxygen delivery device to another, the patient should be restudied to ascertain the appropriate flow rate of oxygen to be delivered. The patient should also be instructed to adjust the oxygen flow rate appropriately when switching from one type of cannula to another.

In summary, we compared a reservoir nasal cannula for delivering oxygen with a standard nasal cannula in 20 hypoxemic patients with chronic obstructive or restrictive ventilatory disease, at rest or during exercise (or both). Our findings indicate that the reservoir nasal cannula produces improvements in SaO₂ similar to those noted with the standard nasal cannula when half or less of the oxygen flow rate was delivered through the reservoir device compared to the standard cannula. These findings indicate advantages of the reservoir nasal cannula over the standard nasal cannula with respect to the cost of ambulatory low-flow oxygen therapy and extended length of time on portable sources of oxygen. A major challenge will be performance of a prospective study to determine if oxygen-conserving cannulas really produce cost-savings in a long-term clinical setting.

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