Effect of Low Flow and High Flow Oxygen Delivery on Exercise Tolerance and Sensation of Dyspnea*

A Study Comparing the Transtracheal Catheter and Nasal Prongs

Naresh A. Dewan, M.D., F.C.C.P.; and C. William Bell, Ph.D.

Hypothesis: We hypothesized that high flow transtracheal oxygen (HFTTO) will improve exercise tolerance as compared with low flow transtracheal oxygen (LFTTO) and that transtracheal oxygen (TTO) will increase exercise tolerance with less dyspnea as compared with nasal prongs (NP) at equivalent oxygen saturation (SaO_2).
Patient selection: Ten subjects, six male and four female, who were already receiving TTO were recruited for the study.
Study design: Each subject underwent a total of four modified progressive treadmill tests in a single-blind randomized fashion on two separate days. Two tests were performed with the patients receiving LFTTO and HFTTO while the other two were performed with low- and high-flow oxygen by NP. The flows were adjusted to provide equivalent oxygen saturations at rest for respective groups.
Results: The mean±SD exercise distance with HFTTO (1,134±631 ft) was 2.5 times greater than with LFTTO (446±328 ft; $p<0.006$); and high-flow NP (HFNP [1207±763 ft]) was 2.38 times greater than with low-flow NP (LFNP[492±487 ft; $p<0.005$]). There was no significant difference in exercise distance and dyspnea scores with HFTTO as compared with HFNP and LFTTO versus LFNP.
Conclusion: We conclude that the use of high-flow oxygen via both transtracheal catheter and NP significantly increased exercise tolerance in our COPD patients when compared to low-flow oxygen. Transtracheal oxygen did not increase maximum exercise tolerance with less dyspnea as compared with oxygen via NP at equivalent SaO_2.

(Chest 1994; 105:1061-65)

HFNP=highflow nasal prongs; HFTTO=high-flow transtracheal oxygen; LFNP=low-flow nasal prongs; LFTTO=low-flow transtracheal oxygen; NP=nasal prongs; TTO=transtracheal oxygen

Previous reports with transtracheal oxygen (TTO) have demonstrated improvements in exercise capacity as judged by exercise time,[1] 12-min walk distance[2] and distance walked on the treadmill.[3] The effect of oxygen flow via transtracheal catheter on exercise tolerance and sensation of dyspnea has not been well studied. A previous study by Couser and Make[4] found significant reduction in inspired minute ventilation $\dot{V}_I$ with TTO. They demonstrated that low-flow TTO (LFTTO) at 2 L/min decreased $\dot{V}_I$ by 28 percent, and increasing the TTO flow to 6 L/min decreased $\dot{V}_I$ further to 49 percent of baseline when TTO is not used. Kollef and Johnson[5] demonstrated that the sensation of dyspnea as measured by the visual analog scale is modified by TTO and transtracheal air and is unrelated to the oxygen saturation (SaO_2) level. It was felt that TTO reduces the inspiratory work of breathing and may be the reason for decreased dyspnea and increased exercise tolerance.

*From the Division of Pulmonary and Critical Care, Department of Medicine, Creighton University, and Veterans Affairs Medical Center, Omaha, Neb.
Manuscript received May 20, 1993; revision accepted September 20.
Reprint requests: Dr. Dewan, Pulmonary and Critical Care Section, Suite 3820, 601 North 30th Street, Omaha, Nebraska. 68131

Based on the aforementioned studies, we hypothesized that high-flow TTO (HFTTO) will improve exercise tolerance as compared with LFTTO and that TTO will increase exercise tolerance with less dyspnea as compared with oxygen via nasal prongs (NP) at equivalent SaO_2.

Methods

Subject Selection

Ten subjects, six male and four female, who were receiving TTO therapy were recruited for the study. All subjects gave informed consent, and the study was approved by the Institutional Review Board for Human Studies.

Design of the Study

Each subject underwent a modified progressive treadmill test protocol. This consisted of an initial work load set at 1 mile per hour (mph)/0 percent grade. The grade was kept constant but the speed was increased by 0.5 mph every 2 min. Endpoints for the exercise test were decreased SaO_2 to less than 85 percent, marked shortness of breath, chest pain, rhythm disturbance, or patient inability to continue. Distance in feet walked on the treadmill was recorded for each study. Sensation of dyspnea was recorded on a numeric Borg[6] scale ranging from 0 to 10. Saturation, dyspnea scores, and heart rate were recorded every minute while the subjects were on the treadmill and during the final seconds of exercise. Subjects also were asked every minute if they could continue with the exercise study.

Downloaded from www.chestjournal.org on January 13, 2009
Copyright © 1994 American College of Chest Physicians

Table 1—*Clinical and Demographic Characteristics of Patients*

Patient No.	Age, yr/Sex	FEV_1, L (% Predicted)	Forced Vital Capacity, L (% Predicted)	Low Flow, L/m		High Flow, L/m	
				NP	TTO	NP	TTO
1	64/M	0.66 (19)	1.81 (37)	3.0	1.75	7	6
2	60/M	0.37 (13)	1.19 (31)	1.5	0.5	3	3.5
3	73/M	1.65 (53)	2.87 (64)	3.0	2.0	8	5
4	63/M	0.67 (29)	1.67 (53)	0.25	0.25	4	4
5	61/F	0.58 (30)	1.58 (61)	1.0	0.5	5	3
6	61/M	0.82 (24)	2.83 (67)	2.5	1.5	8	6
7	55/F	1.43 (67)	2.68 (94)	1.0	1.5	7	7
8	52/F	0.82 (30)	2.10 (62)	3.0	1.0	8	8
9	69/M	0.97 (34)	1.77 (44)	0.5	0.5	4	3.5
10	72/M	1.05 (36)	3.10 (71)	0.5	1.0	5	5
Mean ± SD	63 ± 6.8	0.87 (33) ± 0.44 (18)	2.10 (58) ± 0.65 (19)	1.62 ± 1.3	1.05 ± 0.61	5.9 ± 1.91	5.1 ± 1.64

Each subject underwent a total of four treadmill tests. Two tests were performed with the patient receiving LFTTO and HFTTO while the other two were performed with low- and high-flow oxygen by NP. The flows were adjusted to provide equivalent SaO_2 values at low and high flows. Following are determinations for LFTTO, HFTTO, low-flow NP (LFNP), and high-flow NP (HFNP):

LFTTO—0.25 to 2 L O_2 to maintain SaO_2 92 ± 1 percent at rest
HFTTO—3 to 8 L O_2 to maintain SaO_2 98 ± 1 percent at rest
LFNP—0.5 to 4 L O_2 to maintain SaO_2 92 ± 1 percent at rest
HFNP—3 to 8 L O_2 to maintain SaO_2 98 ± 1 percent at rest

In order to make this a single-blind study, subjects received 0.5 L of airflow via NP when they received TTO and vice versa, 0.5 L of air via transtracheal catheter when they received oxygen via NP. In addition, both air and oxygen flowmeters were hidden from the subject's view. The four tests were randomized and done on two separate days with two tests per visit. Exercise tests were conducted at the same time of the day with a minimum period of 30 min of rest between each test.

Statistical Analysis

All values were expressed as mean ± SD. Differences between low- and high-flow oxygen systems were analyzed by nonparametric Wilcoxon matched pairs signed rank test. A value of $p<0.05$, after adjustment for multiple comparisons, was considered to be statistically significant.

Results

Clinical and demographic characteristics are listed in Table 1. All patients had moderate to severe COPD. Mean ± SD oxygen flow rates for LFTTO and LFNP were 1.05 ± 0.61 L/min and 1.62/ ± /1.3 L/min, respectively; whereas HFTTO and HFNP were 5.1 ± 1.64 L/min and 5.9 ± 1.91 L/min, respectively.

Nine of the ten subjects walked significantly farther on both high-flow systems when compared

Table 2—*Maximum Distance, Dyspnea Score, Saturation, and Heart Rate During Exercise Tolerance Studies*

	Low Flow								High Flow							
	Distance, ft		Dyspnea Score		SaO_2%*		Heart Rate		Distance, ft		Dyspnea Score		SaO_2%*		Heart Rate	
Patient	NP	TTO	NP	TTO	NP	TTO	NP	TTO	NP	TTO	NP	TTO	NP	TTO	NP	TTO
1	97	156	10	7	84†	84†	112	114	112	133	10	7	91†	93†	114	115
2	365	262	1	1	84‡	84‡	100	99	2,238	1,971	10	10	85†	84†	137	140
3	116	147	7	9	84†	84‡	151	147	211	383	5	8	83‡	82‡	152	149
4	530	808	8	7	84‡	84‡	136	142	1,248	1,248	10	7	93†	96‖	146	146
5	902	714	8	3	84‡	84‡	134	137	1,746	1,314	10	10	84†	93†	153	144
6	1,653	1,094	7	6	84‡	84‡	121	106	2,392	2,213	10	10	89†	89†	123	125
7	139	160	.5	.5	84‡	84‡	74	82	703	852	1	1	83‡	84‡	87	90
8	178	319	.5	1	84‡	82‡	141	134	1,248	1,028	4	4	87‖	93‖	152	158
9	275	269	4	3	84‡	83‡	125	125	1,029	1,029	7	6	88†	91†	142	142
10	668	533	5	5	84‡	82‡	110	118	1,139	1,168	10	9	90†	90†	131	121
Mean ± SD	492§ ± 487	446§ ± 328	5.1 ± 3.5	4.3 ± 3.0	84 ± .0	84§ ± .9	120§ ± 23	120§ ± 21	1,207§ ± 763	1,134§ ± 631	7.7 ± 3.3	7.2 ± 2.9	87 ± 3	90§ ± 5	134§ ± 21	133§ ± 20

*End-exercise saturation.
†Exercise study stopped due to shortness of breath with inability to continue.
‡Exercise study stopped due to SaO_2% less than 85%.
§Adjusted $p<0.05$ when comparing HFTTO to LFTTO and HFNP to LFNP.
‖Exercise study stopped due to shortness of breath and leg fatigue with inability to continue.

Downloaded from www.chestjournal.org on January 13, 2009
Copyright © 1994 American College of Chest Physicians

with low flow. Mean distance, dyspnea score, SaO_2, and heart rate were significantly greater with HFTTO and HFNP as compared with LFTTO and LFNP, respectively. Mean ± SD exercise distance with HFTTO (1,134 ± 631 ft) was 2.5 times greater than with LFTTO (446 ± 328 ft; $p<0.006$) and HFNP (1,207 ± 763 ft) was 2.38 times greater than with LFNP (492 ± 487 ft; $p<0.005$). Table 2 shows these results.

Mean distance and heart rate were not significantly different with HFTTO as compared with HFNP and LFTTO versus LFNP. However, one half of the subjects walked farther using LFTTO as compared with LFNP, four subjects walked farther while receiving HFTTO as compared with HFNP, and two walked equal distances. The SaO_2 values at the end of exercise tended to be lower with HFNP when compared with HFTTO, but were equal with LFNP versus LFTTO. Mean ± SD dyspnea scores were not significantly different with HFTTO (7.2 ± 2.9) as compared with HFNP (7.7 ± 3.3; $p<0.34$) and LFTTO (4.3 ± 3.0) versus LFNP (5.1 ± 3.47; $p<0.17$) at the same level of exercise. In a majority of the subjects, the exercise study was terminated either due to desaturation below 85 percent or shortness of breath with inability to continue. Only two subjects expressed shortness of breath and leg fatigue with inability to continue. In the high-flow group, only four of the exercise studies (patients 3 and 7) were terminated due to desaturation (Table 2).

Discussion

Our study clearly demonstrates a significant benefit of HFTTO on maximal exercise capacity over LFTTO. Maximum exercise distance increased by 150 percent with HFTTO when compared with LFTTO ($p<0.006$). However, this benefit was not limited to HFTTO only and patients with HFNP also increased their maximum exercise distance by 138 percent over LFNP ($p<0.005$). This suggests that the benefit of high-flow oxygen was not limited to TTO alone, but high flow supplemental oxygen via both routes improved exercise tolerance over low-flow oxygen.

Previous studies in patients with COPD and hypoxemia have demonstrated substantial benefits in exercise tolerance with the use of supplemental oxygen. Woodcock et al[7] showed a 28 percent improvement in the maximum distance walked on the treadmill with nasal oxygen in the absence of hypoxemia. Davidson et al[8] not only demonstrated an increase in the endurance walking time with supplemental nasal oxygen at 4 L/min, but also showed a dose-dependent increase in mean cycling endurance time, with increases of 50 percent at an oxygen flow rate of 2 L/min, 88 percent at 4 L/min, and 80 percent at 6 L/min. More recently, Dean et al[9] demonstrated an improvement in exercise tolerance with 40 percent supplemental oxygen during cycle ergometry in 12 patients with severe COPD who were not hypoxemic at rest (mean PaO_2, 71 mm Hg). Exercise time was increased with reduction in minute ventilation and mean dyspnea scores. In two patients, dyspnea scores decreased dramatically even though they did not desaturate with exercise while breathing room air.

Possible mechanisms for increased exercise tolerance with supplemental oxygen include reduction in ventilation,[10,11] greater delivery of oxygen to the tissues,[12] and decreased oxygen cost to the respiratory muscles.[13,14] Reduction in ventilation is linked to blunting of the hypoxic drive mediated via the peripheral chemoreceptors.[15] The decrease in oxygen cost of breathing is attributed to lowering of airway resistance which is known to occur with oxygen breathing in hypoxic COPD patients.[16] It thus appears that oxygen administration improves metabolic efficiency of the respiratory muscles with lower minute ventilation at a given work load.

The use of high-flow supplemental oxygen may have a dual beneficial effect on exercise tolerance in hypoxic COPD patients. High flow rates reducing $\dot{V}_I$ is known to occur with TTO and may be a mechanism for decreased work of breathing with TTO[4] and possibly NP.[14] High-flow supplemental oxygen also leads to a higher level of resting SaO_2. An SaO_2 of 98 percent is likely to cause greater suppression of the hypoxic drive than a level of 92 percent.[17] In some patients with COPD, maximal oxygen consumption may be delivery-dependent.[12] Although the increment is small, a higher level of SaO_2 will increase the delivery of oxygen to the tissues. More recently, in a group of patients with chronic heart failure,[18] it was found that increasing the resting mean oxygen saturation from 94.1 to 98.4 percent with 50 percent supplemental oxygen improved the total exercise duration significantly with simultaneous reductions in minute ventilation and dyspnea scores. Results from our study in this group of patients with COPD also demonstrate that increasing the resting SaO_2 from 92 to 98 percent significantly increased their exercise tolerance.

In clinical practice, exercise testing is not performed routinely to determine the oxygen requirement during activity. Most physicians empirically prescribe 1 L/min of additional oxygen over their usual flow for exercise. A recent study by Zimmerman et al[19] demonstrated a significant increase in exercise endurance with nasal oxygen at 6 L/min when

Downloaded from www.chestjournal.org on January 13, 2009
Copyright © 1994 American College of Chest Physicians

compared with their usual flow plus 1 L/min oxygen. This finding supports the results of our study which suggests that higher oxygen flows can increase exercise tolerance in patients with chronic lung disease. These data suggest that exercise testing should be routinely performed in COPD patients, when prescribing long-term oxygen, to determine the optimal oxygen flow during activity to allow maximum exercise tolerance.

The significant improvement in maximum exercise tolerance with high-flow oxygen may be partially attributed to the design of our study protocol. Although the endpoints for our modified progressive treadmill test were shortness of breath, inability of the patient to continue, arrhythmias, chest pain, and desaturation below 85 percent, in a majority of the subjects the study was terminated either due to desaturation below 85 percent or shortness of breath with inability to continue. Patients had substantially lower SaO_2 saturation while receiving low-flow oxygen, both at the beginning and at the end of the exercise study when compared with the high-flow oxygen. Also, patients had lower dyspnea scores while receiving low-flow oxygen, suggesting that they were not exercised to their maximum tolerance. In retrospect, had these patients been exercised to their maximum tolerance, with no regard for their SaO_2 level, patients receiving low-flow oxygen may have demonstrated slightly higher exercise tolerance. It also is conceivable that the two subjects receiving high-flow oxygen in whom the exercise study was terminated due to desaturation, may have walked farther had the flows been further increased. We believe that this factor would have reduced, but not completely eliminated, the beneficial effect of high-flow oxygen.

Contrary to our hypothesis, maximum exercise tolerance and dyspnea scores were not significantly different with HFTTO as compared with HFNP and LFTTO versus LFNP. The similarity in maximum exercise tolerance with HFTTO and HFNP may be attributed to the design of our exercise protocol. A previous study by Wesmiller et al[1] demonstrated an increase in 12-min walk distance when subjects used TTO as compared with supplemental nasal oxygen. The 12-min walk test, which allowed the patients to walk at tolerable speeds, was more a measure of their endurance rather than maximal exercise capacity. The protocol used in our study was a modified progressive treadmill test to determine maximum exercise capacity. In this test, patients were subjected to a higher work load every 2 min and subjects with end-stage COPD with significant ventilatory limitation may not be able to tolerate the increased work load despite the beneficial effects of high-flow oxygen.

In summary, our study has demonstrated that the use of high-flow oxygen via both transtracheal catheter and NP significantly increased maximum exercise tolerance over low-flow oxygen. We were unable to show improved exercise tolerance with HFTTO as compared with HFNP and LFTTO versus LFNP. The results of our study tend to support an emerging concept that some oxygen is good, but more may be better. We believe that an exercise oximetry study should be performed in most patients with COPD to determine the optimum oxygen requirement during exercise. Further studies are needed to compare the effect of low- and high-flow oxygen on exercise tolerance with no regard to the SaO_2 level as an endpoint.

ACKNOWLEDGMENTS: The writers thank Walter J. O'Donohue, Jr., M.D., for helpful suggestions and review of the manuscript; Kay Ryschon, M.S., for statistical analysis, and Dee Peters for secretarial assistance.

References

1 Wesmiller SW, Hoffman LA, Sciurba FC, Johnson JJ, Ferson PF, Zullo TG, et al. Exercise tolerance during nasal cannula and transtracheal oxygen delivery. Am Rev Respir Dis 1990; 141:789-91
2 Bloom BS, Daniel JM, Wiseman M, Knorr RS, Cebul R, Kissick WL. Transtracheal oxygen delivery and patients with chronic obstructive pulmonary disease. Respir Med 1989; 83:281-88
3 Bell CW, O'Donohue WJ, Dewan NA, Campbell JC, Angelillo VA, Anderson B. Effects of transtracheal oxygen therapy on exercise capacity. J Cardiopul Rehab 1988; 11:449-52
4 Couser JI, Make BJ. Transtracheal oxygen decreases inspired minute ventilation. Am Rev Respir Dis 1989; 139:627-31
5 Kollef MH, Johnson RC. Transtracheal gas administration and the perception of dyspnea. Res Care 1990; 35:791-99
6 Borg G. Psychophysical basis of perceived exertion. Med Sci Sports Exer 1982; 14:377-81
7 Woodcock AA, Gross ER, Geddes DM. Oxygen relieves breathlessness in "pink puffers". Lancet 1981; I:907-09
8 Davidson AC, Leach R, George RJD, Geddes DM. Supplemental oxygen and exercise ability in chronic obstructive airways disease. Thorax 1988; 43:965-71
9 Dean NC, Brown JK, Himelman RB, Doherty JJ, Gold WM, Stulbarg MS. Oxygen may improve dyspnea and endurance in COPD patients with only mild hypoxemia. Am Rev Respir Dis 1992; 146:941-45
10 Stein DA, Bradley BL, Miller WC. Mechanism of oxygen effects on exercise in patients with chronic obstructive lung disease. Chest 1982; 81:6-10
11 Swinburn CR, Wakefield JM, Jones PW. Relationship between ventilation and breathlessness during exercise in chronic obstructive airways disease is not altered by prevention of hypoxemia. Clin Sci 1984; 67:515-19
12 Corriveau ML, Rosen BJ, Dolen GF. Oxygen transport and oxygen consumption during supplemental oxygen administration in patients with chronic obstructive lung disease. Am J Med 1989; 87:633-37
13 Mannix ET, Manfredi F, Palange P, Dowdeswell RG, Farber MO. Oxygen may lower the O_2 cost of ventilation in chronic obstructive lung disease. Chest 1992; 101:910-15

Downloaded from www.chestjournal.org on January 13, 2009
Copyright © 1994 American College of Chest Physicians

14 Tarpy S, Epstein S, Gottlieb D, Celli B. The effect of oxygen and air via nasal cannula on oxygen cost of breathing in chronic airflow obstruction (CAO). Am Rev Respir Dis 1992; 145:A646

15 Aubier M, Murciano D, Milic Emili J, Touaty E, Daghfous J, Pariente R et al. Effects of the administration of O_2 on ventilation and blood gases in patients with chronic obstructive lung disease during acute respiratory failure. Am Rev Respir Dis 1980; 122:747-54

16 Libby DM, Briscoe WA, King TKC. Relief of hypoxia-related bronchoconstriction by breathing 30% oxygen. Am Rev Respir Dis 1981; 123:171-75

17 Rebuck AS, Woodley WE. Ventilatory effects of hypoxia and their dependence on PCO_2. J Appl Physiol 1975; 38:16-19

18 Moore DP, Weston AR, Hughes JMB, Oakley CM, Cleland JGF. Effects of increased inspired oxygen concentrations on exercise performance in chronic heart failure. Lancet 1992; 339:850-53

19 Zimmerman LH, Doherty J, Brown JK, Stulbarg MS. Can higher than usual doses of supplemental oxygen improve endurance with exercise in chronically hypoxemic COPD patients. Am Rev Respir Dis 1992; 145:A647

7th World Conference on Lung Cancer

The International Association for the Study of Lung Cancer will present the Seventh Conference June 26-July 1 at the Broadmoor Resort, Colorado Springs. For information, contact Linda Wise, Centennial Conferences, 5353 Manhattan Circle, Boulder, Colorado 80303 (303:499-2299).

Downloaded from www.chestjournal.org on January 13, 2009
Copyright © 1994 American College of Chest Physicians

Effect of low flow and high flow oxygen delivery on exercise tolerance and sensation of dyspnea. A study comparing the transtracheal catheter and nasal prongs.

N A Dewan and C W Bell

Chest 1994;105; 1061-1065

DOI 10.1378/chest.105.4.1061

This information is current as of January 13, 2009

Updated Information & Services	Updated Information and services, including high-resolution figures, can be found at:
Citations	This article has been cited by 3 HighWire-hosted articles: **http://www.chestjournal.org/content/105/4/1061#related-urls**
Open Access	Freely available online through CHEST open access option
Permissions & Licensing	Information about reproducing this article in parts (figures, tables) or in its entirety can be found online at: http://chestjournal.org/misc/reprints.shtml
Reprints	Information about ordering reprints can be found online: http://chestjournal.org/misc/reprints.shtml
Email alerting service	Receive free email alerts when new articles cit this article. sign up in the box at the top right corner of the online article.
Images in PowerPoint format	Figures that appear in CHEST articles can be downloaded for teaching purposes in PowerPoint slide format. See any online article figure for directions.

AMERICAN COLLEGE OF CHEST PHYSICIANS®

Downloaded from www.chestjournal.org on January 13, 2009
Copyright © 1994 American College of Chest Physicians