Short papers

Exhaled NO during graded changes in inhaled oxygen in man

Leopold Schmetterer, Karin Strenn, Johannes Kastner, Hans-Georg Eichler, Michael Wolzt

Abstract
Background – **Nitric oxide (NO) is present in the exhaled air of animals and humans. In isolated animal lungs the amount of exhaled NO is decreased during hypoxia. A study was undertaken to determine whether changes in arterial oxygen tension affect levels of exhaled NO in humans.**
Methods – **Sixteen healthy subjects were randomised to inhale different gas mixtures of oxygen and nitrogen in a double blind crossover study. Eight gas mixtures of oxygen and nitrogen (fractional inspired oxygen concentration (FiO_2) 0.1 to 1.0) were administered. Exhaled NO was measured with a chemiluminescence detector from end expiratory single breath exhalation.**
Results – **A dose-dependent change in exhaled NO during graded oxygen breathing was observed (p = 0.0012). The mean (SE) exhaled NO concentration was 31 (3) ppb at baseline, 39 (4) ppb at an FiO_2 of 1.0, and 26 (3) ppb at an FiO_2 of 0.1.**
Conclusions – **The NO concentration in exhaled air in healthy humans is dependent on oxygen tension. Hyperoxia increases the level of exhaled NO, which indicates increased NO production. The mechanism behind this phenomenon remains to be elucidated.**
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Keywords: exhaled NO, hypoxia, hyperoxia.

Department of Clinical Pharmacology
L Schmetterer
J Kastner
H-G Eichler
M Wolzt

Institute of Medical Physics
L Schmetterer

Department of Ophthalmology B
K Strenn

University of Vienna, Vienna, Austria

Correspondence to:
Dr L Schmetterer,
Department of Clinical Pharmacology,
Währinger Gürtel 18–20,
A-1090 Vienna, Austria.

Nitric oxide (NO) can be detected in the exhaled air of animals and humans.[1–3] Endogenous NO, which is produced by NO synthase from the amino acid L-arginine, may play an important role in the physiology of the respiratory system and in the pathophysiology of airway disease.[4 5] The absolute concentration of NO in expired air is dependent on the technique used to measure the exhalate. Exhaled NO is greater during nose breathing than during mouth breathing[6] and breath holding increases exhaled NO,[7] which suggests accumulation of NO in the upper and lower respiratory tract.

In the pulmonary circulation hypoxia causes pulmonary vasoconstriction in vivo.[8] This effect is specific to the pulmonary vasculature and is presumably mediated by decreased production of endogenous NO.[9] Several investigators have shown that hypoxia decreases exhaled NO levels in isolated animal lungs.[10–12] The aim of the present study was to investigate whether oxygen tension affects exhaled NO levels in humans. However, due to ethical considerations any study on this subject in humans is limited to moderate hypoxia. We have therefore included different grades of hypoxia and hyperoxia in the present study to obtain a dose-response relationship between changes in inhaled oxygen and exhaled NO.

Methods

SUBJECTS
Sixteen healthy, non-smoking, drug-free volunteers (nine men) of mean (SD) age 28.6 (3.2) years (range 23–35) were studied. None of the subjects reported airway hyperreactivity or lung disease in their medical history.

The study protocol was approved by the ethics committee of Vienna University School of Medicine and written informed consent was obtained from all subjects.

PILOT STUDY
In four of the subjects we performed experiments on the effect of inhalation of 100% O_2 and 10% O_2 + 90% N_2 on arterial oxygen tension (PaO_2). PaO_2 was measured at baseline and at the end of 10 minutes inhalation of 10% O_2 + 90% N_2 or 100% O_2. The washout period between the two inhalation periods was 10 minutes. PaO_2 was determined from capillary blood samples of the earlobe.[13] The arterialised blood was drawn into a thin glass capillary tube. Arterial pH, PCO_2 and PO_2 were determined with an automatic blood gas analysis system (AVL 995-Hb, Graz, Austria).

STUDY PROTOCOL
Subjects were randomised to inhale different gas mixtures of O_2 and N_2 in a double blind crossover design. Studies were conducted on a single trial day. The following gas mixtures of O_2 and N_2 were administered: 100% O_2 + 0% N_2, 80% O_2 + 20% N_2, 60% O_2 + 40% N_2, 40% O_2 + 60% N_2, 30% O_2 + 70% N_2, 20% O_2 + 80% N_2, 15% O_2 + 85% N_2, and 10%
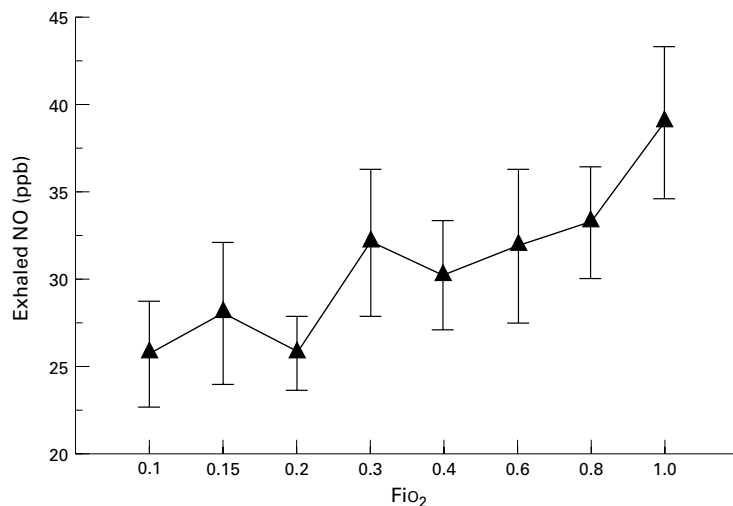
Figure 1   The effect of different mixtures of O_2 and N_2 (FiO_2) on exhaled NO in 16 healthy volunteers. The error bars represent the SE.

O_2 + 90% N_2. Balanced randomisation was used to ensure that groups of two of the 16 subjects received one of the above treatments first. All gases were delivered through a partially expanded reservoir bag at atmospheric pressure under nasal occlusion.

All subjects were asked to refrain from alcohol and caffeine for at least 12 hours before each trial day. After a 20 minute resting period in the sitting position, baseline measurements of exhaled NO and systemic haemodynamics were performed. Thereafter, a 10-minute breathing period of the first gas mixture was started. Measurements were obtained during the last three minutes of each breathing period. Subjects subsequently crossed over to the next treatment where measurements were performed in an identical fashion. The washout period between consecutive inhalation periods was 10 minutes. After four inhalation periods measurements were again performed under resting conditions before crossing over to the other gas mixtures under study. Recordings during breathing of ambient air were repeated at the end of the study. The readouts during breathing of ambient air were taken to calculate short term variability of measurements.

STUDY METHODS
Exhaled NO was measured with a chemi-luminescence detector (Nitrogen oxides analyser, Model 8840, Monitor Labs Inc, USA). Calibration of the instrument was done with certified gases (1000 and 300 ppb NO in N_2, AGA, Vienna, Austria) using precision flow meters. A baseline signal was obtained with pure N_2. With 100% O_2 we did not obtain a signal, which ensured that oxygen itself did not influence the NO readings. One l/min of the exhaled air was allowed to enter the inlet port. Subjects were instructed to fully inflate their lungs, hold their breath for 10 seconds, and exhale for 10 seconds into a Teflon tube. Auto-inhalation of NO from the nasopharynx was avoided by a noseclip. Three consecutive read-

ings were made at each measurement point under nasal occlusion. The end expiratory values from the strip recorder readings were used for analysis to ensure that inspired NO from the ambient air did not distort the results. Previous studies have shown that inhalation of up to 38 ppb NO does not influence the level of exhaled NO after breath holding for 15 seconds.[3] The detection limit of this method is 2 ppb.[14]

Systolic and diastolic blood pressures and pulse rate were measured by an automated oscillometric device (Siemens Sirecust 888R, Siemens, Erlangen, Germany).

STATISTICAL ANALYSIS
Statistical analysis was performed using the Statistica software package (Release 4.5, Stat-Soft Inc, Tulsa, Oklahoma, USA). To quantify the short term variability of the exhaled NO measurements, intraclass correlation coefficients (κ) were calculated from the three recordings under ambient air breathing. κ was calculated according to the method of Kramer and Feinstein[15] based on a repeated measure ANOVA model. κ can then be calculated from the variance among subjects (v_s), the variance among methods (v_m), and the residual error variance (v_e):

$$\kappa = (v_s - v_e)/(v_s + v_e + 2 \times v_m)$$

The higher the intraclass correlation coefficients the better the reproducibility of the method. A κ of 1 reflects perfect reproducibility. The intraclass correlation coefficient is a widely accepted measure of reliability and is considered more appropriate than older methods such as χ^2, percentage agreement, product moment correlation or Yule's Y.[15 16]

The effects of graded changes in FiO_2 on exhaled NO and systemic haemodynamics were assessed by repeated measure ANOVA. Post hoc comparisons were carried out using paired *t* tests. The level of significance was set at p = 0.05. Data are presented as means (SE).

Results
The baseline value of PaO_2 in the pilot experiment was 92 (4) mm Hg (12.3 (0.5) kPa). A mixture of 10% O_2 + 90% N_2 caused moderate hypoxia with a PaO_2 of 45 (2) mm Hg (6.0 (0.3) kPa). In contrast, 100% O_2 raised the PaO_2 to 491 (24) mm Hg (65.5 (3.2) kPa).

Exhaled NO levels at baseline, after the fourth breathing period, and at the end of the study were 31 (3) ppb, 30 (3) ppb, and 28 (2) ppb, respectively (NS). The intraclass correlation coefficient as calculated from these results was 0.63.

The effect of inhalation of the gases with different FiO_2 on exhaled NO is shown in fig 1. There was a positive correlation between changes in FiO_2 and exhaled NO levels (p = 0.0012, ANOVA), with 26 (3) ppb at an FiO_2 of 0.1 and 39 (4) ppb at an FiO_2 of 1.0. An FiO_2 of 0.1, however, did not significantly reduce exhaled NO compared with baseline, as evidenced from post-hoc comparisons.

Systolic blood pressure was 127 (12) mm Hg, diastolic blood pressure was 79 (6) mm Hg, and pulse rate was 79 (11) beats/min at baseline. Systemic haemodynamics showed only minor changes during inhalation periods (data not shown). A significant increase in pulse rate to 87 (7) beats/min was observed only during inhalation of a gas mixture with an Fio_2 of 0.1 (p = 0.023 compared with baseline).

Discussion

The results of this study show that NO in the exhaled air is dependent upon oxygen tension. Hyperoxia during 100% O_2 breathing resulted in an approximately 25% increase in exhaled NO levels compared with baseline. In contrast, hypoxia only slightly reduced exhaled NO. The latter might be caused by at least two phenomena. On the one hand, the reproducibility of our test system may limit the sensitivity to detect small changes in exhaled NO concentration and, on the other, a study in humans is limited to moderate hypoxia and we cannot exclude the possibility that a more pronounced hypoxia would have resulted with lower concentrations of NO in the exhaled air.

It has already been observed in buffer perfused rabbit lungs that hypoxia decreases exhaled NO.[11] In the isolated pig lung hypoxia produced an increase in pulmonary vascular resistance and a fall in exhaled levels of NO.[10 12] The mechanism by which hypoxia and hyperoxia influence exhaled levels of NO remains unclear. An inhibition of NO synthase by pulmonary hypoxia is unlikely because the vasoconstrictor response to hypoxia is intensified by NO synthase inhibition.[17] It has been speculated that hypoxia limits the availability of oxygen for NO synthesis,[12] which is in keeping with the finding that hypoxia inhibits NO synthase through oxygen depletion.[18] However, our results support the concept that endogenously generated NO is involved in hypoxic pulmonary vasoconstriction.

For interpretation of our data it must be considered that the exact origin of NO in exhaled air in healthy humans has not yet been determined. High concentrations of NO have been observed in paranasal sinuses[19] and it is assumed that exhaled NO to some degree reflects NO derived from the upper airways.[20] The endogenous source of exhaled NO is reflected by the reduction in expired NO following inhalation[3 21] and intravenous administration of NO synthase inhibitors[22–25] and the increase after orally[26] and intravenously[24] administered L-arginine. The comparatively high levels of NO measured with our system in exhaled air may be caused by the fact that, on the one hand, autoinhalation of NO, but not the nasal contribution of NO, were avoided by the use of a noseclip and, on the other, breath holding increases NO levels.

In conclusion, we have shown that the NO concentration in exhaled air in healthy humans is dependent on oxygen tension. Hyperoxia increases the level of exhaled NO, which indicates increased pulmonary NO production. The mechanism behind this phenomenon remains to be elucidated.

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