Effect of inhaled L-arginine on exhaled nitric oxide in normal and asthmatic subjects

Maria A Sapienza, Sergei A Kharitonov, Ildiko Horvath, K Fan Chung, Peter J Barnes

Abstract

Background—Nitric oxide (NO) plays an important part in the regulation of many physiological functions and may also be involved in several pulmonary diseases. Endogenous NO is synthesised by different isoforms of NO synthase (NOS) from L-arginine.

Methods—The effect of inhaled L-arginine 0.75 g (six normal and six asthmatic subjects), 1.5 g (six normal and six asthmatic subjects), and 3 g (seven normal and six asthmatic subjects) has been studied in a double blind placebo controlled, randomised, parallel group design study. In addition, the effect of a single dose (3 g) of inhaled L-alanine has been assessed in five normal and five asthmatic subjects.

Results—L-arginine increased exhaled NO in a dose-dependent fashion with a maximum at 60 minutes. The cumulative effect of L-arginine (3 g) on NO in asthmatic subjects, expressed as the area under the curve in arbitrary units (au) and compared with the effect of placebo (0.9% NaCl), was significantly higher (mean 0.11 au; 95% confidence interval (CI) 0.03 to 0.19) than in normal subjects (0.012 au; 95% CI 0.002 to 0.022). There was a negative correlation (r = –0.72) between the increase in exhaled NO and the fall in forced expiratory volume in one second (FEV1) (0.034 au, 95% CI 0.030 to 0.038) after 3 g L-arginine in asthmatic subjects. Inhalation of 3 g of L-alanine produced a similar reduction in FEV1 (0.033 au, 95% CI 0.007 to 0.059) but no significantly different changes in exhaled NO (0.017 au, 95% CI 0.001 to 0.039) compared with placebo (0.020 au, 95% CI 0.001 to 0.042).

Conclusions—An increase in the amount of substrate for NOS increases the formation of endogenous NO. L-arginine may have therapeutic potential in diseases in which there is defective production of NO, but in asthma it may amplify the inflammatory response in the airways.

Keywords: nitric oxide; L-arginine; asthma

Nitric oxide (NO) is a gaseous mediator which plays a key role in the physiological control of the airways and in the pathophysiology of airway diseases. It is present in the exhaled air of animals and humans and the concentration of exhaled NO is increased in patients with asthma and bronchiectasis. NO may be derived from different cells in the respiratory tract and appears to be involved in a large range of functions including vascular regulation, neurotransmission, host defence, and cytotoxicity. Endogenous NO is synthesised from the amino acid L-arginine by the enzyme NOS. There are three different isoforms of NOS. Constitutive enzymes (cNOS) have been found in endothelium and neurons and are activated by a rise in intracellular calcium in response to physiological stimuli. An inducible calcium-independent enzyme (iNOS), which may be expressed after induction with cytokines and endotoxin in a number of cell types, is increased in the airway epithelium of asthmatic patients and its expression can be reduced by glucocorticoids. In the pulmonary circulation NO is synthesised in endothelial cells by an endothelial NOS (eNOS). Endogenous NO may have a different role in the airways. When produced in small amounts by cNOS activation it may be beneficial in relaxing airway smooth muscle, but it may have deleterious effects when produced in higher concentrations from iNOS. NO is a potent vasodilator and may contribute to the plasma exudation and to the hyperaemia of asthmatic airways. On the other hand, high concentrations of NO provide a non-specific defence mechanism in the respiratory tract and it has been shown that knock-out mice that lack the iNOS gene are significantly more susceptible to infections. L-arginine has been used in the long term treatment of arginine succinate deficiency and may also prevent some complications of diabetes mellitus. Moreover, it has been suggested that L-arginine improves the impaired coronary microcirculation of hypercholesterolaemic subjects. These effects of L-arginine may be due to increased formation of endogenous NO. We have previously shown that oral L-arginine increases exhaled NO in normal subjects. Since L-arginine is the substrate for NO synthesis, we have investigated the effect of inhaled L-arginine and another amino acid, L-alanine, which is not a substrate for NOS, on exhaled NO in normal and asthmatic subjects. We also investigated the dose-response relationship between inhaled L-arginine and exhaled NO.

Methods

PATIENTS

Twenty four healthy subjects (14 men) and 23 patients with stable asthma (15 men) were recruited. All were non-smokers who had no history of respiratory or cardiovascular disease and were not receiving long term medication. Patients with stable asthma had positive skin prick tests (>3 mm) for at least two common inhaled allergens and baseline forced expira-
tory volume in one second (FEV$_1$) was $>70\%$ of the predicted. Subjects had increased airway responsiveness, defined as a provocative concentration of methacholine causing a 20% reduction in FEV$_1$ (PC$_{20}$) of $<8$ mg/ml. None was using concomitant medication except for on-demand inhaled short acting $\beta$ agonists. There was no history of upper respiratory tract infection for at least four weeks prior to the study. Subjects did not consume any caffeine for two hours before the L-arginine medication. All subjects gave their written consent to the study which was approved by the ethics committee of the Royal Brompton Hospital.

**STUDY DESIGN**

Before entering the study all subjects were seen on a screening visit during which a questionnaire, PC$_{20}$ methacholine, and skin prick tests were performed. The study consisted of two visits separated by an interval of three days. On each study day a single dose of L-arginine (Sigma, Poole, Dorset, UK) was inhaled. Subjects received 0.75 g (six normal, six asthmatic subjects), 1.5 g (six normal, six asthmatic subjects), or 3 g (seven normal, six asthmatic subjects). The three study doses were dissolved in different volumes of normal saline (0.75, 1.5 and 3 g of L-arginine in 10, 20, and 40 ml, respectively) to obtain a concentration of 0.075 mg/ml (pH 5.5, mOsm 664). L-arginine or normal saline control (also in volumes of 10, 20, or 40 ml) was inhaled via an ultrasonic nebuliser (DeVilbiss, Heston, UK; output 4.7 ml/min) whilst wearing a noseclip. An additional group of five normal and five asthmatic subjects inhaled a single dose (3 g) of L-alanine (Sigma, Poole, Dorset, UK) (pH 5.9, mOsm 836) dissolved in 40 ml of normal saline, or 40 ml of normal saline, during two different occasions separated by an interval of three days. Inhalation delivery was designated time 0 and exhaled NO and FEV$_1$ were measured before medication and then every 30 minutes for five hours. Pulse and supine blood pressure were measured before and 30 minutes after administration of treatment. The study was designed in a double blind, placebo controlled, randomised, parallel group fashion.

**EXHALED NITRIC OXIDE MEASUREMENTS**

Exhaled NO was measured using a modified chemiluminescence analyser (Logan Research LR2000; Rochester, UK) sensitive to NO from 1 ppb (by volume) to 5000 ppb and with a resolution of 0.3 ppb, which was designed for on-line recording of exhaled NO concentration as previously described. In addition to NO, the analyser also measures carbon dioxide (resolution 0.1% CO$_2$; response time 200 ms) and sample pressure and volume in real time. The sampling rate of the analyser was 25 ml/min for all measurements. The analyser was calibrated using certified NO mixtures (90 ppb and 500 ppb) in nitrogen (BOC Special Gases, Guildford, UK). Measurements of exhaled NO were made by slow exhalation (5–6 l/min) from total lung capacity for 15–20 s against a mild resistance to exclude nasal contamination. The value corresponding to the plateau of the end-exhaled CO$_2$ reading (5% CO$_2$) was taken as representative of an alveolar sample. In these measurements the pressure during expiration was kept constant (3 (0.4) mm Hg) by using a visual display of expiratory flow measured by pressure and volume sensors in the analyser.

**PULMONARY FUNCTION AND METHACHOLINE PROVOCATION TESTS**

FEV$_1$, and forced vital capacity (FVC) were measured using a dry spirometer (Vitalograph, Buckingham, UK), the best of three manoeuvres.
Airway responsiveness was measured in asthmatic subjects by methacholine provocation challenge. The solution was nebulised with a hand-held nebuliser (Dosimeter MB3; MEFAR Bovezzo, Italy) with an output of 100 µl. The PC_{20} was calculated by interpolation of the logarithmic dose-response curve.

**DATA ANALYSIS**

The cumulative effect of L-arginine, placebo, or L-alanine was expressed as the area under the curve. Estimates of difference between L-arginine and placebo or L-alanine and placebo were presented as mean differences with 95% confidence intervals. Comparisons between the groups were made by a paired t test. A p value <0.05 was considered significant.

**Results**

There was a dose-dependent increase in exhaled NO with a maximal effect at 60 minutes in asthmatic subjects (fig 1B) but not in normal subjects (fig 1A). The pattern of NO change following 0.75 g and 1.5 g L-arginine was the same as for the highest dose (fig 4A and B). There was no significant change in FEV_{1} after L-arginine administration at these two doses (1 (2.1)% and –10 (3.4)%, respectively, p>0.05).

**Discussion**

Our study shows that inhaled L-arginine induces a significant increase in exhaled NO in normal and asthmatic subjects suggesting that there is evidence of a change in the activity of endogenous NOS in response to increased availability of substrate. The increase in exhaled NO was dose-related in asthmatic subjects but not in normal subjects and was also more significant in asthmatic subjects than in normal subjects. This may reflect differences in sensitivity of endogenous NOS to different doses of L-arginine between normal and asthmatic subjects. The increased exhaled NO in asthmatic patients is likely to be due to increased expression of iNOS which has a greater utilisation of L-arginine than constitutive enzymes as it results in greater NO production. The increase in exhaled NO was maximal at 60 minutes after administration of L-arginine by inhalation. The main source of NO is not yet certain but there is some evidence to suggest that high concentrations of NO are formed in the nasopharynx and this may be related to the high density of blood vessels in the nasal mucosa. NO may be also derived from the airway epithelium, the alveoli (epithelium or endothelium), or inflammatory cells such as macrophages. Previously we have reported that the increased levels of NO found in patients with asthma are derived predominantly from the lower respiratory tract. Moreover, we have shown that the administr-
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