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Challenge test for sulfur dioxide — Symptom and lung function measurements

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The use of challenge tests in environmental exposure chambers has given much information about the noxious effects of gaseous pollutants and the safety of exposure limits in recent years (1, 4). In this paper we report the methods used for gaseous pollutants in the environmental exposure chamber at the National Board of Occupational Health, Division of Occupational Medicine, Umeå, Sweden. The purpose of this investigation was to establish standardized procedures for exposure to sulfur dioxide (SO_2) and to study the mucosal and airway effects of this gas in comparison with air exposure.

Subjects and methods

Eight healthy, nonsmoking subjects, age 21—29 years, with normal lung function and gas distribution participated in this investigation. None of them had a history of a recent airway infection or a history of bronchial hyperresponsiveness.

The exposure chamber measured 3.20 × 2.00 × 2.20 m with an air volume of 14.1 m³. It was built with anodized aluminum, with windows in one wall. Ambient air was drawn continuously through the chamber at 400 m³/h, resulting in one air exchange approximately every 2 min. Preexposure measurements have shown very low levels of particulate matter in the chamber. During the exposures, the chamber air temperature was kept at 20°C, and the relative humidity at around 50 %.

The SO_2-air atmosphere in the exposure chamber was generated by addition of a gas stream from a 1 % SO_2 gas tube to the chamber air inlet. The chamber air was continuously analyzed with coulometric titration (3). This is a method in which air containing $SO_2(g)$ is bubbled through an electrochemical cell filled with a water solution of 0.40 % potassium iodide and 0.68 % acetic acid. The $SO_2(g)$ is then oxidized to SO_4^{2-} by I_2. The reaction displaces the equilibrium between the redox couple I^- and I_2, which causes the cell potential to change. This change is recorded by an indication circuit consisting of a reference electrode made of platinum. To compensate for this change, a current is sent through the generation circuit, where both the anode and the cathode are made of platinum. The produced current is proportional to the amount of SO_2 and is registered on a recorder. The method makes it possible to follow the SO_2 concentration in the chamber continuously and to avoid the concentration deviating from what is intended.

The subjects were exposed to air and to SO_2 air concentrations of 1, 5, and 10 mg/m³ (0.4, 2, and 4 ppm, respectively) in the exposure chamber. They had no knowledge of the exposure levels. The total exposure time was 20 min. During the first 5 min in the chamber the registration electrodes on the test subjects were adjusted by a technician. For the remaining 15 min the subjects worked on a bicycle ergometer with a work load of 75 W.

Heart rate was recorded with a six-channel electrocardiographic recorder (Siemens-Elema, Sweden) with the electrodes placed in the CR_1 and CR_2 locations on the chest with a reference electrode located on the forehead.

A continuous recording of the breathing pattern was obtained from a thermistor in one nostril of the subjects. The thermistor recorded the temperature changes of the breathing air even during oral breathing.

Two methods were used in parallel for the objective assessment of eye symptoms. A video camera with a tape recorder was used throughout the test, and the frequency of eye blinks was calculated. Eye blinks were also recorded with electrooculography.

Before, during, and at the end of the exposure, the test subjects were asked about airway, eye, and mucosal symptoms according to a standardized questionnaire using Borg's category scale (2).

Spirometry was performed immediately before and after each chamber exposure with an OHIO rolling seal dry spirometer measuring forced vital capacity (FVC), forced expiratory volume in 1 s ($FEV_{1.0}$), 25—75 % of forced expiratory flow (FEF_{25-75}), and mean transit time (MTT). The gas distribution and closing volume were recorded with a single-breath nitrogen washout method with an OHIO nitrogen analyzer 720, and the alveolar plateau (% N_2/l) was calculated.

Wilcoxon's nonparametric signed rank test was used.

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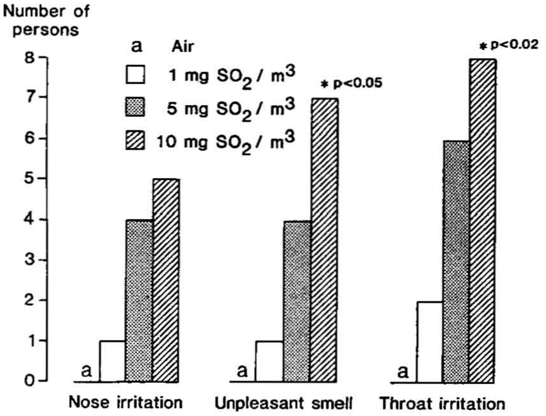

Figure 1. Symptoms of the nose and throat of eight healthy subjects at the end of exposure to air and to sulfur dioxide concentrations of 1, 5, and 10 mg/m³ in comparison to before exposure.

Results

The heart rate during work was 90—100 beats/min, and the breathing frequency was 18—23 breaths/min. No differences were seen between different exposure levels.

The two methods for measuring eye blink frequency corresponded well. The inter- and intraindividual difference in blink frequency was considerable, and no significant divergence between doses was found. Mild eye symptoms, mild breathlessness, and cough were reported by a few subjects but without dose dependency. A dose-dependent increase in nasal irritation was found, but only five of eight subjects reported this symptom at the highest dose.

Irritation from the throat was significantly more common during than before SO_2 exposure at 5 mg/m³ ($P<0.05$). It was more frequent during and at the end of the SO_2 exposure at 10 mg/m³ than before exposure ($P<0.02$) and also more commonly reported at the end of exposure at 10 mg/m³ than at the end of 1 mg/m³ SO_2 exposure ($P<0.05$) (figure 1). The symptoms scored from the throat were mild during all the exposures. An unpleasant smell was more commonly reported at the end than before exposure to 10 mg/m³ ($P<0.05$).

Dynamic airflow, measured as $FEV_{1.0}$, FEF_{25-75}, FVC, gas distribution, and closing volume was not significantly affected in any individual after the air or SO_2 exposure (table 1).

Discussion

The conditions in the environmental chamber and the study protocol are well in agreement with work situations in, eg, the paper mill industry, and they are easily adjusted to fit other work conditions (5, 7, 8). During the series of experiments the SO_2 concentrations were accurately maintained with the aid of continuous monitoring of the SO_2 concentration in the chamber. As expected, the subjects perceived a moderate but increasingly unpleasant smell with increasing SO_2 concentration. A dose-dependent irritation of the throat was found, but the symptoms were relatively mild. Breathing pattern and eye symptoms were not affected. No significant changes were seen in the lung function of any subject even after exposure to 10 mg/m³, a concentration which is slightly lower than the Swedish short-term exposure limit of 13 mg/m³. Changes in airflow and airway reactivity have, however, been demonstrated with more sensitive techniques (6, 9).

It was concluded that environmental chamber exposure is a good method for studying the effects of gaseous pollutants. The chamber and protocol used are suitable for further investigations with bronchoalveolar lavage, which presently appears to be the most advantageous and sensitive method for evaluating noxious effects of irritant gases in the lungs of man. Such studies are in progress in our laboratory.

Table 1. Lung function of eight healthy subjects before and after chamber exposure to air and to an air concentration of sulfur dioxide of 10 mg/m³. (FVC = forced vital capacity, $FEV_{1.0}$ = forced expiratory volume in 1 s, FEF_{25-75} = 25—75 % of forced expiratory flow, MTT = mean transit time, $\Delta\%N_2/l$ = change in alveolar plateau, Q_1 = first quartile, Q_3 = third quartile)

	FVC		$FEV_{1.0}$		FEF_{25-75}		MTT		$\Delta\%N_2/l$	
	Median	Q_1—Q_3	Median	Q_1—Q_3	Median	Q_1—Q_3	Median	Q_1—Q_3	Median	Q_1—Q_3
Before exposure (% of normal values)	108	101—119	91	86—106	64	52—85	114	112—134	50	42—72
After air exposure (% change of initial value)	0.7	−0.6—1	0	0—2	−2	−5—4	0	−8—8	6	−4—18
After exposure to sulfur dioxide of 10 mg/m³ (% change of initial value)	0.1	−0.5—3	2	−3—4	2	−7—10	2	−6—7	0.6	−5—6

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