Air Pollution and Disease

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The disastrous smogs that struck London in 1948 and 1952, the Meuse Valley in 1930 and Donora in 1948, spurred concern over the relation between the air we breathe and our health. This concern has been reflected in increasing epidemiologic and laboratory investigations of polluted air, as well as in legislative actions to curb the sources of pollution. The present article, as an introduction to the subject, offers a classification of air pollution, indicates gases and particles known to damage the lungs, and describes some of the acute functional responses of the lungs to irritants.

Atmospheric pollution can be separated into three major types: general, occupational and personal. General or community atmospheric pollution is one to which the entire population of an area, rural or urban, is exposed. The more significant sources of this type of pollution are shown in Table 1. Some of these sources are gradually being eliminated: oil, gas and electricity are replacing coal as a home fuel; and communities are now substituting well-designed incinerators for smoke-producing dumps.

Examples of contaminants, that are known to cause disease, if present in sufficient concentration, are sulfur dioxide, beryllium and fluoride. Others, like soot and ash, constitute aesthetic as well as economic blights. The annual cost of removing such dirt from clothes, buildings and other properties is estimated in billions of dollars. Mercaptans, another nuisance, impart offensive odors at concentrations as low as a few parts per billion parts of air (by volume).

Occupational pollution is, with few exceptions, a hazard to only the persons at work. It is usually more concentrated than general pollution. Most occupational pollutants enter the body through the respiratory system. They include dusts (silica, cotton, flax), fumes (zinc oxide, lead oxide) and gases (SO₂, Cl₂, NO₂). Respiratory diseases may result from exposure to relatively high doses for short periods of time (the acute pneumonitis of beryllium intoxication) or from protracted exposures to relatively low concentrations (silicosis in quarrying and mining).

The third type of “pollution” is personal which we consider, for practical purposes, to be tobacco smoking. It has received little attention until the recent past, and yet it deserves the most concern of all forms of pollution. Several studies in the United States and in other countries have implicated cigarette smoking as an important factor in lung cancer. There is evidence, too, that smoking contributes to the incidence of chronic nonspecific respiratory disease and cardiovascular disorders. The latter two associations are, in fact, responsible for more illness and deaths than lung cancer. Because of the influence of cigarette smoking in the causation of respiratory disease, it is necessary to eliminate the bias resulting from cigarette smoking if one hopes to assess the effects of general or occupational atmospheric pollution.

It should be understood that general pollution may differ significantly from one place to another in mode of onset, composition and effects on health. For example, the pollution typical of Los Angeles is associated with warm, sunny weather, whereas that of London is severest in cold and fog. In Los Angeles the sun’s energy causes a series of complex (and not fully understood) reactions among the original pollutants and successively among the products of these reactions. Irritants like ozone and aldehydes are continually being

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**Table 1. Types of Atmospheric Pollution**

<table>
<thead>
<tr>
<th>Type</th>
<th>Source</th>
<th>Selected Contaminants</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Automobile</td>
<td>Oxides of nitrogen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrocarbons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3-4 Benzpyrene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO</td>
</tr>
<tr>
<td>Homes (coal burning)</td>
<td>Smoke, CO, CO₂, SO₂</td>
<td></td>
</tr>
<tr>
<td>Industries</td>
<td>Smoke, Ash, Soot, SO₂, H₂SO₄, F₃, Be, ZnO, CdO, CO, CO₄</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mercaptans</td>
</tr>
<tr>
<td>Natural:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants—trees</td>
<td>Pollens—Allergens</td>
<td></td>
</tr>
<tr>
<td>Volcanoes</td>
<td>Ash, SO₂</td>
<td></td>
</tr>
<tr>
<td>Forest fires</td>
<td>Smoke, aldehydes</td>
<td></td>
</tr>
<tr>
<td>Open Dumps</td>
<td>Ash, smoke, aldehydes</td>
<td></td>
</tr>
<tr>
<td>Occupational</td>
<td>Industries</td>
<td>Chemical dusts, gases, fumes and vapors.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic dusts,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e.g., cotton, flux, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(See table 3)</td>
</tr>
<tr>
<td>Personal</td>
<td>Cigars, cigarettes, pipes</td>
<td>Smoke, oxides of nitrogen, tars</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radioactive particles</td>
</tr>
</tbody>
</table>

liberated or formed. These products are responsible for the irritation of the mucous membranes of the eyes and throat. A comparison of two types of general atmospheric pollution is contained in table 2. The examples are an oxidizing type like Los Angeles' and a reducing type such as occurs in London.

Whatever the components of polluted air may be, their concentrations and injurious effects increase dramatically in the presence of meteorologic “inversions.” An inversion is defined as a layer of (cooler) air that is overlaid by a layer of warmer air. As a consequence, the warmer air acts as a blanket preventing dispersion of pollutants (if any are present) from the cooler, dependent level. Inversions may occur near the ground when the earth cools the air just above it; this is typical of London and is called a radiation type of inversion. They may also form at varying altitudes whenever a layer of air settles and thereby compresses and heats itself

**Table 2. Comparison of Two Types of General Atmospheric Pollution**

<table>
<thead>
<tr>
<th></th>
<th>Los Angeles Type</th>
<th>London Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °F.</td>
<td>75–90</td>
<td>30–40</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>70</td>
<td>85 + fog</td>
</tr>
<tr>
<td>Type of inversion</td>
<td>Subsidence</td>
<td>Radiation</td>
</tr>
<tr>
<td>Time of year</td>
<td>August–September</td>
<td>November–January</td>
</tr>
<tr>
<td>Maximum level of pollution</td>
<td>Mid-day</td>
<td>Night to early A.M.</td>
</tr>
<tr>
<td>Sources</td>
<td>Hydrocarbons from automobiles and industries</td>
<td>Industry, coal burning homes and locomotives</td>
</tr>
<tr>
<td>Components</td>
<td>Organic peroxides</td>
<td>SO₂</td>
</tr>
<tr>
<td></td>
<td>Ozone</td>
<td>H₂SO₄</td>
</tr>
<tr>
<td></td>
<td>Oxides of nitrogen</td>
<td>Soot and ash</td>
</tr>
<tr>
<td></td>
<td>Aldehydes and ketones</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrocarbons</td>
<td></td>
</tr>
<tr>
<td>Amount of ash, tons/mile/month</td>
<td>20–30</td>
<td>120–180</td>
</tr>
<tr>
<td>Chemistry</td>
<td>Oxidizing</td>
<td>Reducing</td>
</tr>
</tbody>
</table>
and the air immediately beneath it. This is called a subsidence type and is found in Los Angeles. In Los Angeles this stagnation is enhanced by the surrounding mountains.

A follow-up study of persons living in Donora at the time of the 1948 smog showed that those who were made acutely ill by the episode were more likely in the subsequent ten-year period to experience greater morbidity and mortality than were persons who, originally, showed no ill effects. The unresolved question is whether the acute episode ultimately caused respiratory illness or merely exacerbated existing illness, or both. The relation of intensity of air pollution to respiratory symptoms has been carefully documented in a survey by British general practitioners. Fluctuations in the level of atmospheric pollution have shown significant correlation with the number and severity of symptoms in patients having chronic respiratory disease. A study in the United States showed that the frequency of respiratory infections lasting over seven days in female employees correlated significantly with SO₂ levels in the community.

Unlike air pollution that, primarily, is chemically reducing (SO₂) the oxidizing variety (ozone) characteristic of Los Angeles does not appear to be a factor in the causation of chronic respiratory disease. It does irritate the mucous membranes of the eyes and throat, and affects pulmonary function in patients with respiratory disease. But even in periods of heavy, sustained pollution, there has been no increased mortality or morbidity in the susceptible elements of the population, i.e., elderly persons and patients with respiratory disease. High concentrations of ozone and the oxides of nitrogen (in silos) have been shown to cause pulmonary disease in man. It is possible that longer exposure to current or even higher levels of pollution in Los Angeles may ultimately contribute to the incidence of pulmonary disease.

In addition to inversions, other types of weather may influence the effect of pollutants. Fog appears to increase the association between air pollution and respiratory disease. This association may, in fact, reflect the effects of stagnant air (and rising levels of pollution) rather than any specific role of the fog droplets. The possible influence of droplets on the effects of irritant gases will be discussed later in this paper.

The Effect of Air Pollution on Human Health is an excellent review for those who wish a detailed discussion of the subject.

Occupational air pollution can be an important factor in the genesis of acute or chronic disease. A detailed examination of this type of pollution is beyond the scope of this presentation. It is appropriate, however, to present in summary form some of the categories that seem most important. Table 3 presents these categories and some examples that can cause disease in man.

The effects vary from local irritation and increased bronchomotor tone to the later production of severe pulmonary fibrosis. Severe pulmonary fibrosis has been reported in man as a result of exposure to oxides of nitrogen (in farmers) and to the fibrogenic dusts (asbestos, silica). Acute massive exposure to certain gases, such as Cl₂ or phosgene, can cause pulmonary edema and, if death does not occur, may result in permanent respiratory impairment.

It thus becomes necessary to inquire into the occupational history of the patient to determine the materials to which he may have been exposed and whether he has developed any impairment of respiratory function.

There is an excellent review by British authors on the relation between tobacco smoking and health. In the past, and perhaps even now, most emphasis was placed on the possibility of getting cancer of the lung. We should like to point out the relation between smoking and chronic nonspecific respiratory disease. Table 4, from the report of Anderson and Ferris demonstrates that rates of respiratory disease corrected for age are lowest in non- and ex-smokers, intermediate in pipe and cigar smokers and highest in cigarette smokers. Table 5, presenting only the data for cigarette smokers, shows an increasing prevalence of respiratory disease with increasing current cigarette smoking. The prevalence of disease in males and females shows a parallel pattern when smoking histories are similar. Figure 1 presents the relationship between the relative risk of developing respiratory disease and the life-time consumption of cigarettes. The nonsmoker's rate is used as
Table 3. Categories of Airborne Materials with Selected Examples That May Occur in Industry and That May Cause Disease

Gases and Vapors

I. Irritants
   A. Primary Irritants—site and rapidity of action, a function of solubility in water.
      1. Upper respiratory tract—highly soluble—prompt action
         Ammonia
         Hydrochloric acid
         Hydrofluoric acid
      2. Upper and lower respiratory tract—moderately soluble—slow action.
         Sulfur dioxide
         Chlorine, bromine, iodine, and fluorine
      3. Those acting primarily upon lungs—low solubility—delayed action.
         Ozone
         Oxides of nitrogen
         Phosgene
   4. Organic vapors not following general rules as to solubility in relation to site of action.
      Arolein
      Dimethyl sulfate
      Halogenated organic compounds

B. Secondary Irritants
   Hydrogen sulfide
   Volatile hydrocarbons
   Pyridine
   Ethylene oxide

II. Asphyxiants
   A. Simple Asphyxiants
      1. Inert physiologically at sea level or at altitude—not by displacing oxygen.
         Hydrogen
         Nitrogen
      2. Slight specific action; inhaled in high concentrations act as asphyxiants.
         Methane, ethane, propane
         Ethylene
         Nitrous oxide
   B. Chemical Asphyxiants
      Carbon monoxide—combines with hemoglobin
      Cyanides—poison cellular enzymes
      Hydrogen sulfide—paralyses respiratory center

III. Volatile Organic and Inorganic Substances
   A. Primary Anesthetics
      Hydrocarbons of saturated, olefinic and acetylenic series
      Ethers
      Aldehydes and ketones
   B. Injure chiefly nervous system
      Methyl alcohol
      Carbon disulfide
      Tetra-ethyl lead
   C. Injure chiefly visceral organs—Liver or kidneys
      Halogenated hydrocarbons (carbon tetrachloride)
   D. Injure chiefly hematopoietic system
      Benzene and homologs
   E. Act principally on blood and cardio-vascular system
      1. Predominantly "nitrite effect" (dilatation of peripheral arteries resulting in lowered blood pressure and accelerated heart rate). Secondary effect is conversion of oxyhemoglobin to methemoglobin.
      Alkyl nitrites
      Alkyl nitro-substitution products
### Table 3.—(Continued)

2. Predominant action is conversion of oxyhemoglobin to methemoglobin with little "nitrite effect."
   - Amino compounds
   - Aromatic nitro-substitution products

3. Hemolytic
   - Arsine HAs

F. Sensitizing
   - Toluene di-isocyanate

<table>
<thead>
<tr>
<th>FUMES</th>
<th>DUSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Beryllium—lungs, liver, spleen, lymph node, kidneys</td>
<td>A. Apparently non-fibrogenic</td>
</tr>
<tr>
<td>B. Cadmium—lungs, kidneys</td>
<td>Aluminum (?)</td>
</tr>
<tr>
<td>C. Lead—bone, peripheral nerves, central nervous system, blood</td>
<td>Barium—Baritosis</td>
</tr>
<tr>
<td>D. Mercury—kidneys, central nervous system</td>
<td>Calcium</td>
</tr>
<tr>
<td>E. Phosphorus—kidneys, bone</td>
<td>Carbon—(Graphite)</td>
</tr>
<tr>
<td>F. Zinc oxide fumes—metal fume fever</td>
<td>Coal—Coal worker’s pneumoconiosis</td>
</tr>
<tr>
<td></td>
<td>Iron—Siderosis</td>
</tr>
<tr>
<td></td>
<td>Tin—Stannosis</td>
</tr>
</tbody>
</table>

B. Inorganic—fibrogenic—in lungs
   - Aluminum (?) |
   - Asbestos—Asbestosis |
   - Diatomaceous earth |
   - Kaolin |
   - Mica |
   - Silica—Silicosis |
   - Tale |

C. Organic Dusts
   - Cotton, flax, hemp—Byssinosis—Fibrosis |
   - Hay—Farmer’s lung, Thresher’s lung |
   - Sugar cane—Bagassosis |
   - Castor bean pumice—(Ricin) |
   - Pollens | apparently due to mould. |

D. Carcinogenic Dusts and Vapors
   - Certain chromates |
   - Nickel |
   - Asbestos |
   - Arsenicals |
   - Coal tar and petroleum derivatives |
   - Isopropyl oil |
   - Ionizing radiation |

E. Infections
   - Anthrax |
   - Aspergillosis |
   - Coccidiomyces |
   - Histoplasmosis |
   - Tuberculosis |

the standard and is assigned the value of one. With increasing life-time smoking the risk rises for both sexes; in the range of 3,001–9,000 packs there is an abrupt rise in risks of disease for both men and women. The “point” at which this rise occurs may represent a threshold concentration, or perhaps a change in smoking habits, characterized, for example, by
Table 4. Age Standardized Rates of Respiratory Diseases by Tobacco Usage and Sex

<table>
<thead>
<tr>
<th>Tobacco Smoking Habits</th>
<th>All Respiratory Disease</th>
<th>Chronic Bronchitis</th>
<th>Irreversible Obstructive Lung Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
</tr>
<tr>
<td>Never smoked</td>
<td>18.1</td>
<td>17.2</td>
<td>13.8</td>
</tr>
<tr>
<td>Ex-smoker</td>
<td>18.4</td>
<td>19.2</td>
<td>11.0</td>
</tr>
<tr>
<td>Currently smoking pipe &amp;/or cigars</td>
<td>31.0</td>
<td>—</td>
<td>26.0</td>
</tr>
<tr>
<td>Currently smoking cigarettes</td>
<td>50.9</td>
<td>31.0</td>
<td>40.3</td>
</tr>
<tr>
<td>Currently smoking pipe &amp;/or cigar and</td>
<td>54.6</td>
<td>—</td>
<td>39.6</td>
</tr>
<tr>
<td>cigarettes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>40.1</td>
<td>21.6</td>
<td>31.0</td>
</tr>
</tbody>
</table>


deep inhalation. It is equivalent to smoking 1-2 packs a day for about ten years. It appears that female cigarette smokers are just as susceptible to chronic respiratory disease, as defined in that study, as male cigarette smokers. It is probable that a sex difference in cigarette smoking habits can account for the different rates of lung cancer in the two sexes. Cigarette smoking is more deleterious than

Table 5. Age Standardized Rates (Percentage) of Respiratory Disease by Current Cigarette Smoking Habits and Sex

<table>
<thead>
<tr>
<th>Current Cigarette Smoking Habits</th>
<th>All Respiratory Disease</th>
<th>Chronic Bronchitis</th>
<th>Irreversible Obstructive Lung Disease*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Never smoked</td>
<td>19.7</td>
<td>17.2</td>
<td>15.0</td>
</tr>
<tr>
<td>Ex-smoker</td>
<td>24.8</td>
<td>19.2</td>
<td>18.9</td>
</tr>
<tr>
<td>1-10/day</td>
<td>43.1</td>
<td>20.0</td>
<td>29.8</td>
</tr>
<tr>
<td>11-20/day</td>
<td>47.5</td>
<td>35.3</td>
<td>34.2</td>
</tr>
<tr>
<td>21-30/day</td>
<td>51.1</td>
<td>42.3</td>
<td>—</td>
</tr>
<tr>
<td>31-40/day</td>
<td>71.1</td>
<td>43.4</td>
<td>61.1</td>
</tr>
<tr>
<td>41 plus/day</td>
<td>87.7</td>
<td>75.3</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>40.0</td>
<td>21.6</td>
<td>31.0</td>
</tr>
</tbody>
</table>

* Rates in parenthesis are for subjects who did not report co-existing heart disease.

cigar or pipe smoking, probably because cigarette smoke is more likely to be inhaled. Interestingly, there is evidence that this association with chronic respiratory disease requires that smoking be current, table 4. The ex-smoker is not worse off than the nonsmoker. A regression of the cellular changes induced in bronchial epithelium by cigarette smoke has also been reported in persons who have given up smoking. 

It is probably fair to conclude that cigarette smoking (personal pollution) here and in other countries is responsible for more respiratory disease than is community pollution. It is a concern that is important to the personal physician as well as to the epidemiologist. On the other hand general air pollution has been responsible for causing respiratory disease and has exacerbated existing respiratory disease. The exact role that general air pollution plays in the causation is still to be defined. In order to determine this role a variety of studies have been done on laboratory animals and human volunteers to study the action of specific contaminants during acute exposures.

**Laboratory Investigations**

A few generalizations are in order about the acute effects of respiratory irritants on pulmonary function. Functional changes may occur in the absence of symptoms. It is thought, however, that even small functional changes can be disabling or life-threatening when superimposed on existing cardiorespiratory disease. Little is known about the importance of repeated functional impairments on the onset and development of chronic respiratory disease. To what extent brief alterations in ciliary movement and in the production and flow of mucus may reduce resistance to infection or magnify the effects of irritants is still moot. Another uncertainty is whether repeated administration of the same irritant to a human subject might evoke an unvarying response, or whether adaptation or an increased sensitivity might ensue.

Changes in respiratory mechanics, that is, pulmonary flow resistance and pulmonary compliance, are useful indices of physiologic responses to inhaled irritants. There is an impressive list of gases and particles that acutely alter these mechanical characteristics of the lungs in human subjects and in laboratory animals. The list includes common elements of air pollution (whether it be general, occupational or personal): SO₂, ozone, NOₓ, NH₃, chemically inert particles such as carbon dust, Al(OH)₃, and carboxyl, chemically reactive particles like H₂SO₄, irradiated autoexhaust fumes, and tobacco smoke in the absence of nicotine. Persons having a history of allergy or of sensitivity to SO₂ may respond with severe bronchospasm. Ciliary activity and flow of mucus are depressed in laboratory animals by SO₂, NH₃, and HCHO.

The solubility of an irritant gas and the size, shape and density of an irritant particle will influence where these inhalants are deposited in the respiratory system and, therefore, to some degree, the type of response they evoke (table 3). Cases that are relatively soluble, such as NH₃ and SO₂, are absorbed largely in the upper airways; they are rarely associated with pulmonary edema unless massive exposure has occurred. Less soluble gases such as chlorine and phosphene characteristically cause pulmonary edema and may eventually result in fibrosis. As particles increase above a micron in diameter they become more subject to gravitational forces: inertial impaction and settling are the modes by which they deposit. Below about 0.1 micron in diameter, measurements of lung volumes related to the time (peak flow rates, timed vital capacity, etc.) reflect the mechanical properties of the lungs and thoracic cage and might be expected to be less sensitive indices of response to toxic agents than are these direct measurements.
they approach the behavior of gas molecules and deposit owing to random Brownian movements. Larger particles (several microns or more in diameter) are mostly filtered out by the upper airways; the nose with its irregular configuration and its hair is particularly effective. Some elongated shapes such as asbestos particles that may be 50 microns long and 1 micron in diameter penetrate as far as the alveoli, much as logs flowing in a stream; they are selectively deposited in the lower lobes of the lungs.

The possibility that different components of polluted air may interact to cause a greater response than could be accounted for by the sum of effects from individual components (potentiation) or that this interaction may lead to a diminished response (attenuation) has been explored in a number of experiments. Evidence has been found in guinea pigs that the mechanical changes of the lungs induced by SO_2 and HCHO are potentiated when submicronic droplets of NaCl are administered simultaneously; the droplets by themselves elicit no response. It is not known whether this potentiation is caused by chemical interaction between the particles and gases (the possibility that traces of impurities may have catalyzed the conversion of SO_2 to H_2SO_4 has not been ruled out) or is due to a physical association between the two so that the gas is either deposited with the particles in more sensitive areas or is concentrated at the site of deposition. In human subjects virtually the same combination of NaCl droplets and SO_2 causes no greater functional changes than does the gas alone.

**Mechanism of Response.** The mucosa of the tracheo-bronchial tree in laboratory animals contains chemo-receptors and mecanoreceptors. Stimulation of either reflexly induces changes in broncho-motor tone. The efferent impulses for these reflexes are transmitted by the vago-sympathetic nerves; these impulses are considered to be largely responsible for the increase in airway resistance associated with inhalation of most respiratory irritants. Other pathways may be involved as indicated by the following evidence: atropine does not always abolish the response, particularly to the administration of soluble gases like NH_3 or SO_2; excised lungs (without extrinsic nerve supply) react to irritants with an increase in airway resistance; stimulation of portions of the brain, of aortic and carotid chemoreceptors, and of the surface of the body may also affect airway caliber.

The regulation of tracheo-bronchial smooth muscle tone is the subject of a recent extensive review. The mechanism whereby the acute insults of prolonged low level exposures produce disease is not clear. Certainly the increased secretion of mucus can be explained. This increased mucus in association with decreased ciliary activity may allow significant concentrations of pollutants to accumulate in the tracheo-bronchial tree and to produce the progressive changes of degeneration and mutation in the bronchial epithelium reported by Auerbach. Additionally, this decreased flow of mucus may foster infections with secondary destruction of tissue or increased local concentration of contaminants and eventually irreversible changes result.

**Summary**

Atmospheric pollution can be classified under three headings: general, occupational and personal. The components are complex and variable so that it is difficult to extrapolate the prevalence of disease in one area to that of another unless the two have similar chemical compositions. Significant exposures can occur at work and may produce impairment of respiratory function. It is emphasized that tobacco smoking, and particularly cigarette smoking, is a most important factor in the causation of chronic nonspecific respiratory disease. Much research has been done to elucidate the mechanism whereby such changes are induced but specific answers concerning the mechanisms have not been forthcoming.

**References**

4. Chronic bronchitis in Great Britain, a national survey carried out by the Respiratory Dis-


