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AND ITS EFFECTS ON THE RESPIRATORY SYSTEM

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GEORGE H. GILL

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WITH 17 ILLUSTRATIONS

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PREFACE

Study of the literature dealing with the effects of dust on the respiratory system is complicated by the extremely wide range of science which is covered. This subject involves medical science regarding effects on the human system ; mineralogical and chemical science to consider the composition of the dust, and physical science to deal with the properties of the particles and their distribution in the atmosphere.

Prolonged investigations have been carried out under the direction of the Medical Research Council, and their published reports are of a highly technical nature, being intended for experts in the various branches of the sciences involved.

Apart from these experts, there are many people who for various reasons are interested in the subject, but find the literature difficult to understand. It is for such persons that this review has been compiled, with the object of providing a groundwork upon which a more detailed study could follow, if required.

A general knowledge of the structure and functions of the lungs is vital as a foundation for study, and the initial section of this review is based upon standard works on physiology. The effects of various types of dust in the lungs and theories for specific reactions are based mainly upon the published reports of the Medical Research Council, translated so far as possible into relatively simple language.

G. H. G.

May, 1947.

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All dust is injurious if breathed in excessive quantity, and particles of dangerous size in a dusty atmosphere may be invisible, thus creating a false sense of security.

It should not be assumed that prolonged exposure of the worker to a low concentration of dust has the same ultimate effect as an equivalent total weight inhaled in short exposures at higher concentration Intermittent exposure to intense dust clouds may be highly dangerous.

Particle Size

Particles in a sample of dust are measured under the microscope in microns, there being 1,000 microns to a millimetre, and for comparison it might be noted that a human hair is 60 to 90 microns in diameter. The normal unaided human eye at a distance of 10 inches with good lighting, can see individual particles of about 50 microns diameter, but is unable to distinguish details of shape. Much smaller particles can be seen if brightly illuminated against a black background, or as " motes " in a sunbeam.

Swallowed Dust

A proportion of the dust breathed is swallowed and, if not of a poisonous or infectious nature, generally produces no permanently harmful effects. Experiments suggested that 75 per cent. might be swallowed with the remaining 25 per cent. passed to the respiratory system. Poisoning from inhaling is much more likely than from swallowing as poison in the lungs passes directly into the blood stream, when it is then pumped by the heart to all parts of the body.

Nasal Filter

Insects, fibres and relatively large dust particles are trapped by the thick hairs in the nostrils. Finer particles which have passed the nostrils may stick to the mucus-coated surfaces in the maze of passages in the cavity of the nose. They are then moved back to the nostrils or to the throat. The efficiency of the nose as a dust filter may be very high even on small particles of 0.5 to 2 microns as shown by experiments made on a large number of persons. It was found that 63 per cent. of the healthy subjects retained over 40 per cent. of the dust in their noses, and the range of efficiency over all the subjects was from 10 to 70 per cent.

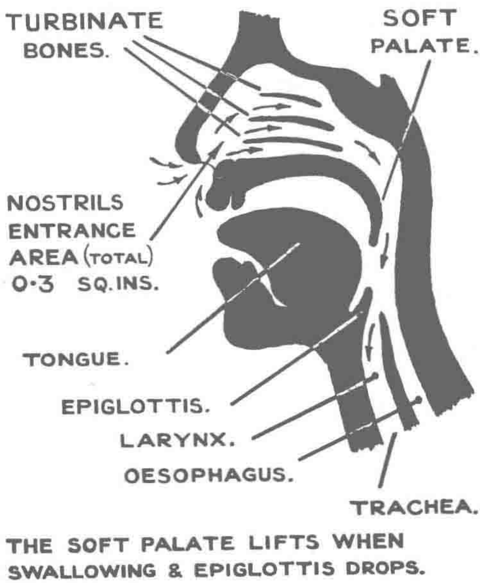

FIG. 1.

AIR FLOW IN THE NOSE.

Effects of Dust

Inhalation of dust can produce four distinct effects :—

1. Coughing and Expectoration, or chronic bronchitis, caused by relatively large particles which irritate the lining membrane of the upper air-tubes. In time this may result in serious inflammation, and dry cough may then occur when permanent damage has been caused to the membrane.

2. Shortness of Breath, or dyspnœa, in varying degree on exertion, caused by small particles which reach the depth of the lungs, there producing reactions which result in damage to the delicate structure, or alternatively blocking the smaller air tubes. This reduces the active surface area of the lungs for oxygenation of the blood and disability may persist as partial or be progressively impaired.

3. Spasmodic Breathing, of transient nature, caused by dusts which affect directly the respiratory control mechanism, or by damage to the lungs which indirectly upsets the normal rhythmic action.

4. Poisoning of the System, caused by toxic dusts which pass their poison through the extensive lung membrane into the circulating blood.

Chest and Lungs

Before considering in detail the various effects of dust, it is essential that the general construction and operation of the lungs should be understood.

The thorax, or chest, Fig. 2, contains the lungs and the heart. It is divided into independent right and left air-tight cavities by a central tissue partition in which run the gullet, blood-vessels, nerves, etc. These cavities are made air-tight by a lining membrane firmly attached to the walls, the lungs being covered by a similar membrane, with their contact surfaces lubricated by a small quantity of watery fluid to reduce friction.

Each lung is attached to the body only at its main air tube, or bronchus, and otherwise is free to move in its cavity which it fills. The cavities can be enlarged or contracted in volume by muscular movement of the diaphragm or ribs to produce respiration.

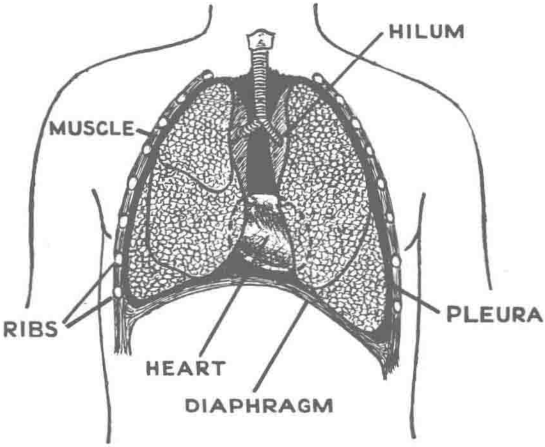

FIG. 2.

THORAX OR CHEST.

During inspiration the diaphragm descends and the hinged ribs are lifted by contraction of their muscles, thus increasing the volume of the cavities. The highly elastic spongy bags of the normal lungs follow by suction this movement of the cavity walls and air is drawn into them.

Expiration is a more or less passive action by relaxation of the muscles, this reducing the volume of the chest. It is probable that the process is rendered smooth in operation by contraction of muscles antagonistic to those concerned in inspiration. Muscle-operated movement is under more delicate control with the provision of a pull and a counter-pull acting on opposite sides of a member.

In forced expiration many muscles are brought into action, such as those of the abdomen, and it should be noted that in forced inspiration accessory muscles may be needed such as those passing from the arms to the thorax. A person suffering from shortness of breath grasps the sides of his chair in an endeavour to fix his arms and thus increase the muscle action. Alternatively when standing he may press his hands tightly against his thighs for the same reason.

Blood Circulation

The muscles of the body in contracting to perform work absorb oxygen from the blood and give off carbon dioxide, the blood supply being regulated in accordance with local requirements. Even when not working, all muscles are kept in a state of incipient contraction, or "tonus," requiring a small supply of oxygen to maintain.

When a person is standing, and idle, the whole of the blood is pumped through his lungs once a minute, this flow rising to eight times a minute on the extremely heavy exertion of trained athletes. In average persons the blood flow through the lungs is about 1 gallon per minute when standing; $2\frac{1}{4}$ gallons a minute at moderate effort equivalent to fairly fast walking, and $5\frac{1}{2}$ gallons a minute when performing an abnormally heavy task. For comparison, a kitchen cold water tap, full on, passes about 4 gallons a minute.

Respiration

To provide the necessary input of oxygen to the blood in accordance with the degree of muscular effort, requires a carefully regulated supply of air into the lungs. This is 16 cubic feet per hour, measured at 70° F., when sitting; 22 when standing; 40 at general light tasks and up to 100 for the average really heavy worker. Athletes require a greater supply of air up to 200, or more, cubic feet per hour.

Now the quantity of air handled is subject to two variables; the frequency of respiration and the depth of respiration. Either can be varied at will, within limits, but the total quantity of air handled, over a period, is outside voluntary control and is automatically adjusted to the requirements of the body. Experiments have been made on a man who varied the frequency of respiration in stages from 3 to 60 per minute, with the depth left to adjust itself in each test. Examination of the results shows that as the frequency was increased, the volume of air was increased for the same bodily requirements. This indicates that with less depth of breathing the air is not so effectively put into the lungs to do its work in the oxygenation of the blood. For example, increasing from 20 per minute to 30 per minute needed 15 per cent. more air volume to do the work.

A normal man breathes at a frequency of about 17 per minute when standing at rest, 20 at light tasks and 26 at heavy work, whilst men on athletic exertion may reach 60 per minute. This varies with individuals, but the figures given are average for general types not in dusty atmospheres.

The normal respiration cycle for a healthy sedentary man is shown in Fig. 3. The chart is based upon tests made recently in America.

Workers in dusty air develop the habit of shallow and rapid breathing as a natural protective instinct, and in time lose the powers of using their lungs efficiently if deep breathing is not practised when away from work.

Control of Respiration

The total volume of air is controlled fundamentally by the chemical composition of the blood passing through the respiratory centre in the brain. In addition, the muscles of respiration are influenced by nerve control, either voluntarily, within limits, or by involuntary reflex action. As the lung expands, it lengthens in radial lines from its point of attachment, and somewhere in the walls of the bronchial tubes, what are known as stretch-receptors are thought to send impulses to the control centre when stimulated by the degree of stretching. It is probable that there are two sets of these receptors, inspiration-inhibiting and inspiration-inducing, their impulses to the control centre causing motor-nerves to co-ordinate the action of muscles during periods of heavy respiration.

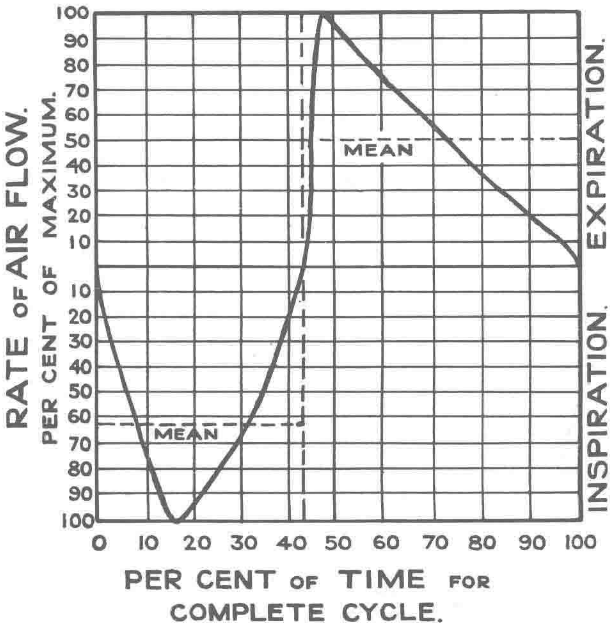

FIG. 3.
RESPIRATION CYCLE.

Experiments have shown that when the inward impulse nerves to the respiratory centre are severed, rhythmic movement of the lungs still continues, but at a constant and much less frequency with greater depth. The maximum possible air volume which can be handled in these conditions is much less than normal.

It is considered also that the air tubes in the lungs have a muscular rhythmic dilation in inspiration and constriction in expiration, but the cause is not known.

Oxygen Deficiency

In shallow breathing more air is required for a given amount of work, this being due to defective distribution, which is also the case if part of the structure is damaged, or some section blocked. It would be thought that if one section of the lung had a greater supply of air than normal and another section a less than normal supply, then the mixed blood from them would be oxygenated at an average value corresponding to normal. This is not so. Blood in contact with air can take up only a definite percentage of oxygen, so that over-ventilation, or an excess of air in relation to the blood flow, cannot over-oxygenate it. But under-ventilation means there is not enough oxygen to supply the blood in that section, and, therefore, the final mixture of blood is part normal and part under normal which may produce a condition of anoxæmia in the person. This is defined as a deficiency of oxygen in the arterial blood.

Respiration Fatigue

People whose lungs are not in good order, with consequent deficiency in oxygenation of the arterial blood, feel that they want more air, and when trying to breath deeper are troubled by the reflex restriction which may give the effect of " an iron band round the chest."

Shallow breathing for long periods, coupled with attempts at work, produces fatigue in the respiratory centre which causes progressively shallower and more frequent respiration with such discomfort that the person is compelled to rest.

Lung Circulations

The hilum or root of each lung is the distributing centre where the ducts of the various circulations enter or leave. These circulations are :—

1. Blood-Gas Exchange Circuit. Dark venous, or de-oxygenated blood is pumped from the heart via the pulmonary artery into the lungs. In the very extensive capillary network in the walls of the air cells carbon dioxide is exchanged for oxygen, and re-

oxygenated bright scarlet blood returns via the pulmonary vein to the heart.

2. NUTRITION BLOOD CIRCUIT. The lung tissues require nutrition which is supplied by an independent circulation of oxygenated blood direct from the heart via the bronchial artery, returning via the bronchial vein.

3. LYMPHATIC CIRCUIT. Following the course of the arteries and veins in the lung tissue is a drainage system. These blood vessels are porous to some extent and filtered blood fluid, known as lymph, is exuded, which after passing through the surrounding tissue drains into the lymphatic system. The lymph is collected by small blind-ended capillaries which start in the lung tissue, converging with others into oval organs acting as filtering centres, known as lymph nodes. These nodes have single duct outlets which again converge at further nodes, finally uniting into a major lymphatic duct which discharges into the main venous blood return circuit to the heart.

4. NERVE CIRCUIT. The sensory impulse nerves and motor response nerves control the respiratory muscles, the calibre of the bronchial tubes and the calibre of the blood vessels.

Lung Construction

The trachea, or wind-pipe, is a flexible tube about $4\frac{1}{2}$ inches long and $\frac{3}{4}$ to $\frac{1}{2}$ inch diameter, tapering slightly in its length with a cross-section like a horseshoe. It is made up of 16 to 20 C-shaped incomplete cartilage rings connected by soft fibrous tissue and muscle. At the upper extremity is the larynx with two elastic fibrous bands stretched across it forming the vocal cords.

Each normal lung is divided into upper and lower lobes by an oblique fissure which penetrates almost to the root. The upper lobe on right side is further divided by a nearly horizontal fissure and thus, instead of two lobes, it has three ; upper, middle and lower. The outer surfaces are smooth and shiny, marked by pigmented lines into irregular areas, roughly $\frac{1}{4}$ to $\frac{3}{4}$ inch diameter, indicating the bases of secondary lobules. At birth the lungs are pink, but become mottled reddish-grey to almost black with age, due to inhalation of dust. When inflated to maximum by a very deep inspiration their total volumetric capacity for a healthy young man is about 5,400 c.c., but normally the capacity ebbs and flows between 2,900 and 3,500 c.c. during quiet breathing. By making a very deep expiration the total capacity can be reduced to a minimum of about 1,600 c.c.

Vital Capacity

What is called the vital capacity is obtained by taking the maximum forced inspiration and then measuring the volume of air in a breath to the limit of maximum forced expiration. In average persons this is from 1,500 to 3,600 c.c., with the general majority about 2,000 to 3,500 c.c. By training, and particularly in swimmers, the vital capacity can be increased, and may reach 5,500 c.c.

Bronchial Tree

The bronchial tree is shown diagrammatically in Fig. 4. Actually the distribution is very much more ramified, and there are millions of the fine branches. These tubes are embedded in tissue in the lobes of the lungs, and are surrounded by the vast multitude of air cells to which they are connected.

Details of the primary and secondary bronchi are shown in Fig. 5. These tubes are star-fish shaped and have a muscular network which enables their area to be adjusted by nerve control. The stiffening rings of cartilage are absent in the smaller tubes, but the muscular network persists to the end of the respiratory bronchioles. Defective control, which results in over-constriction of the tubes, causes distress in breathing, especially in expiration. Certain drugs affect the muscular control of tube calibre.