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THE ASH OF SILICOTIC LUNGS.

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Dr. S. West in his treatise on "Diseases of the Organs of Respiration," in discussing Pneumonokoniosis, points out that Pearson in 1813 suggested that dust particles gain access to the lung tissue. This was disputed at the time and later, but in 1866 Virchow acknowledged that the proof was incontrovertible. West also states that "dusts are not equally irritating. Charcoal may cause little change except pigmentation, while steel dust, and especially silica, is usually associated with advanced and widespread changes."

The underground workers of the gold mines on the Witwatersrand (Transvaal) are exposed to dust-laden air; there are several contributory causes to the dust, amongst which the most important are blasting and drilling. The rock which has to be mined consists mainly of silica (quartzite), but is accompanied by an appreciable amount of aluminium compounds. As no reliable data exist concerning the amount and composition of the ash of lungs of miners affected with the disease known as miners' phthisis or silicosis it was deemed expedient to supplement Dr. W. Watkins-Pitchford's pathological investigation of such lungs by a chemical examination of the ash. I am entirely indebted to Dr. Watkins-Pitchford for the material for the investigation.

A brief description of the circumstances which cause the underground workings of the Witwatersrand mines to be "dusty" places is set forth in Dr. Watkins-Pitchford's address before the Cape of Good Hope (Western) Branch of the British Medical Association ("South African Medical Record," 1914, xii., 33-50): Dr. Watkins-Pitchford also discusses the prevalence of silicosis and the mechanism by which silica particles gain access to the lung tissue. Dr. J. Moir, who has had many opportunities of examining the dust in the under ground workings of the mines, informs me that the dust created by machine-drills contains, as would be expected, a much higher proportion of fine particles than does that created by hand-drills.

Before proceeding to the experimental results it may be advisable to record here some previous observations on the quantity and composition of lung-ash.

West (v. supra) quotes Kussmaul as having found that the ash of the normal lung of infants contains no silica, but as age advances the amount of silica increases. He further found that in the case of quarrymen and men occupied in sandy trades the amount of silica rose to from 40 to 50 per cent. of the total ash.

Arlidge (Milroy Lectures, "Lancet," 1889, i., 615) quotes an analysis, by Church, of a potter's lung: Silica, 47·78 per cent.; Alumina, 18·63 per cent.; Iron oxide, 5·35 per cent., the remanider consisting of alkalis,phosphates, etc.

Oidtmann (v. Gorup-Besanez, Lehrbuch, 4th edition, 732) found that the lungs of a 14-day old child contained 19·82 per cent. of dry matter with 0·57 per cent. of mineral matter: the dry matter, therefore, contained 2·88 per cent. of ash.

Schmidt (ibid. 727) found the following constituents in the ash of normal human lung: 13·0% NaCl, 1·3% K_2O, 19·5% Na_2O, 1·9% CaO, 1·9% MgO, 3·2% Fe_2O_3, 48·5% P_2O_5, 0·8% SO_3, and 13·4% sand.

H. G. Wells (Chicago) in his "Chemical Pathology" (1907), in discussing Pneumonokoniosis, has collected the following data: Woskressensky (Cent. f. Path., 1898, 9, 296) found silicates in all of 54 lungs examined, except in two from infants. The lungs of individuals whose occupations do not expose them especially to dust inhalations contain increasing amounts of silicates in direct proportion to age; the silicates constitute from 3·5 to 10 per cent. of the total ash of the lungs. Thorel (Zieglers Beitr., 1896, 20, 85) reports that the lungs of a worker in soapstone were found to contain 3·25 per cent. of ash, including 2·43 per cent. of soapstone. Hodenpyl (Medical Record, 1889, 56, 942) obtained the following results with the lung of a knife-grinder who had followed his trade for about 15 years: Dry weight of lung, 48·1009 grams; total solids, 44·7986 grams. Composition of the ash: 27·1% SiO_2, 2·0% Fe_2O_3, 32·9% Al_2O_3, 2·2% CaO, 7·9% Na_2O, 4·9% K_2O, 21·4% P_2O_5, and 1·6% SO_3.

For the present investigation six lungs removed from the cadavers of miners who had suffered from silicosis were available. In all cases the right lung was taken for examination. For comparison, a precisely similar examination was made with the right lung removed from the cadaver of a male Zulu, aged 30, who had never worked underground and whose lungs presented entirely normal appearances on post-mortem examination: in the sequel this lung is referred to as "normal."

The procedure was as follows: On removal of the lung from the cadaver the wet weight was determined. The lung was then immersed in boiling water and the boiling was continued for some time. The first immersion in the hot water caused an immediate coagulation over the surface of the lung and so prevented anything but a negligible extraction of soluble salts. The lung was now minced and well dried in the steam-oven. The weight of the dry matter was then determined; no very great accuracy is claimed for this dry weight as no particular pains were taken to dry to constant weight.

Since the deposition of foreign mineral matter in the lung tissue is probably not uniform it was deemed advisable to ash the whole lung rather than risk the possibility of error in ashing only a portion which might not be representative of the whole. The ashing was carried out in a large platinum basin by first igniting over a free flame and subsequently burning off the carbon in a muffle furnace at a dull red heat.

The first table gives the results obtained, and in addition the amount of silica (calculated from the subsequent analysis): the weights are expressed in grams.

TABLE I.

Case	Normal.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Wet weight	649	907	1928	1672	1335	1497	1998
Dry weight	76	200	336	232	215	208·5	233·5
Ash	3·77	9·078	21·706	12·70	20·00	13·55	15·20
Silica	0·55	2·79	6·38	5·19	9·60	6·21	6·57
Ash: % of dry matter	4·96	4·54	6·46	5·47	9·30	6·49	6·51
Silica: % of ash	14·7	30·7	29·4	40·8	48·0	45·8	43·2
Silica: % of dry matter	0·73	1·39	1·90	2·23	4·47	2·98	2·81

The material described as "silica" is mainly silica, but may contain small amounts of very refractory silicates.

The weight of a healthy lung on removal from the body is extremely variable, but as a rough average a weight of 700 grams may be taken as normal for the right lung of an adult male. The high wet weights of the silicotic lungs are due, not entirely to the presence of a large amount of fibrous tissue, but also to their carrying an excess of serous fluid.

It will be observed that (1) the total weight of silica in the diseased lungs was much higher (from 2·8 to 9·6 grams) than in the normal lung (0·55 gram), and (2) the proportion of silica in the ash of the diseased lungs is much greater (from 29 to 48 per cent.) than in the normal lung (14·7 per cent.).

ANALYSIS OF THE ASH.

The ash from cases No. 1 and 2 was white, or nearly so; that from case No. 5 had a faint pink tinge; that from case No. 6 had a faint red tinge. The ash from the normal lung was slightly reddish, and the ashes from cases No. 3 and 4 were markedly red, corresponding with the comparatively high proportion of ferric oxide which they contained.

Ordinary mineral analysis of the ashes gave the following percentages of the constituents named:

TABLE II.

Case	Normal.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Silica	14·71	30·70	29·38	40·86	48·02	45·82	43·20
Ferric oxide	7·34		2·51	9·83	8·49	3·78	3·90
Alumina	5·47		5·50	7·71	9·59	7·90	7·72
Lime	10·98		5·55	3·64	2·16	2·45	4·40
Magnesia	2·66		1·54	1·47	1·64	1·62	1·41
Soda (Na_2O)	18·31		14·10	11·20	6·42	9·16	9·11
Potash (K_2O)	10·04		6·84	4·63	6·07	5·82	4·60
Phosphoric oxide (P_2O_5) ...	19·84		20·82	19·87	16·47	23·50	25·24
Sulphuric oxide (SO_3) ...	2·02		1·14	0·50	0·36	0·24	0·20
Chlorine				0·47	0·17		

It has already been pointed out (in connection with Table I.) that the amount of silica in the ash is greater in that from the silicotic lung than in that from the normal lung. From the fact that the lungs of infants contain no silica and the great probability that practically all the silica which accumulates in the lung during life gains access through inhalation of dust-laden air, it must be admitted that silica is a substance foreign to the lung. If this foreign substance be eliminated from the ash-analyses the following figures are obtained for the percentages of constituents in the ash-other-than-silica:

TABLE III.

Case	Normal.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Ferric oxide	8·6	3·5	16·6	16·3	7·0	6·9
Alumina	6·6	7·8	13·0	18·4	14·6	13·6
Lime	12·9	7·9	6·1	4·1	4·5	7·8
Magnesia	3·2	2·2	2·5	3·2	3·0	2·5
Soda	21·5	20·0	19·0	12·3	16·9	16·0
Potash	11·8	9·7	7·8	11·7	10·7	8·1
Phosphoric oxide	23·2	29·5	33·6	31·7	42·9	43·0
Sulphuric oxide	2·4	1·6	0·8	0·7	0·4	0·4
Chlorine			0·8	0·3		

Inspection of these figures shows that the amount of iron oxide varies irregularly, but the amount of alumina is increased in the silicotic lungs; this increase would be expected because alumina, in varying proportion, accompanies silica (as aluminium silicate) in the dust-laden air inhaled by underground workers. A noticeable feature of the results is the diminished proportion of lime in the diseased lungs as compared with the normal: the amount of magnesia is approximately constant. With regard to the alkalis there is indication of a slight diminution in the silicotic lung, but the decrease is not sufficient to be significant. The most striking fact which is brought to light by Table III. is the marked increase in the proportion of phosphoric oxide in the silicotic lungs: it is not improbable that this increase is associated with the great production of fibrous tissue which takes place (Watkins-Pitchford, *loc. cit.*, p. 46) as silicosis proceeds.

SIZE OF SILICA PARTICLES.

It is important to know the size of the silica particles which, inhaled in the dust, are deposited in the lung tissue. Dr. Watkins-Pitchford suggested that this should be ascertained by dissolving away the tissue in such a manner as to leave the silica particles untouched. In order to carry this out a portion of the left lung of case No. 5 was digested with hydrochloric acid and potassium chlorate until the tissue and all organic matter were destroyed. It is presumed that this process is entirely without action on the silica, and leaves it in its original condition; it may also leave some refractory silicates unchanged, but will dissolve practically all other inorganic matter. When the action was complete the residual white deposit was thoroughly washed by decantation so as to remove all soluble salts; care was taken that sedimentation was complete before decanting, and this was aided by centrifuging the suspension. The white residue was then dried carefully at a low temperature so that no splintering of the silica particles should take place by excessive sudden heating. In this way about a gram of silica powder was obtained.

A smooth thin emulsion of the powder was made and submitted to microscopic examination. Examination with the polarising microscope proved that the material was silica.

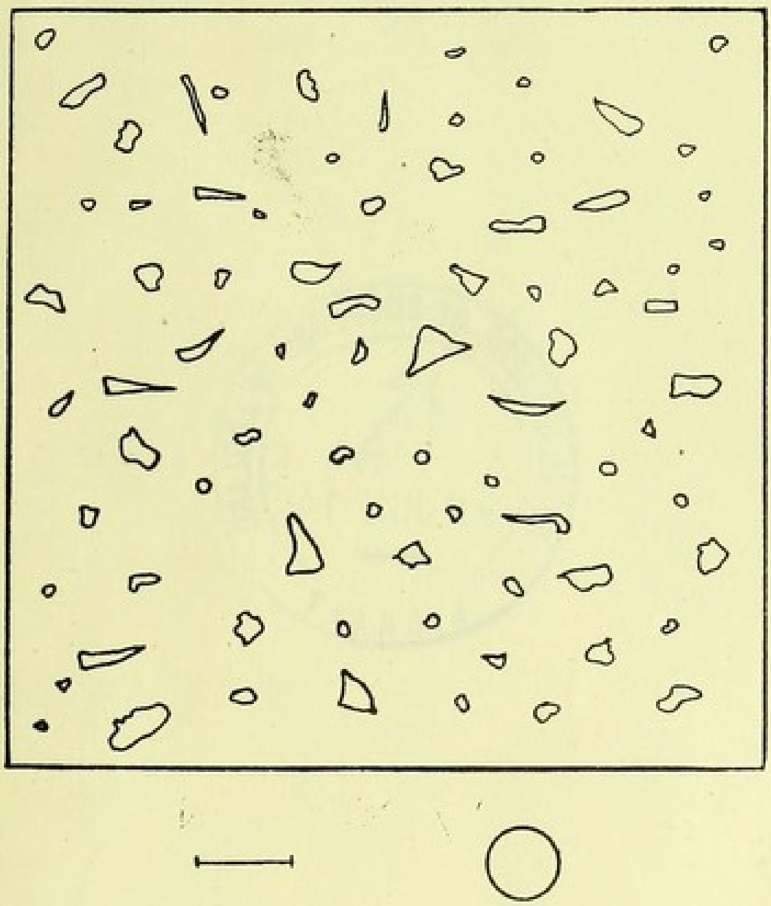
The great majority of the particles were found to be of indefinite shape and to have a diameter less than 1μ (that is, a diameter less than 1/8 of that of a red blood corpuscle); the amount of material with diameter less than 1μ was very approximately 70 per cent. of the whole. No attempt was made to measure diameters less than 1μ. Many measurements were made of the particles constituting the remaining 30 per cent. of the material: the longest diameters of these particles varied between 1μ and $8{\cdot}5\mu$. In an extensive survey of several microscope preparations only a negligibly small number of particles was seen whose longest diameter exceeded $8{\cdot}5\mu$, and the very longest observed was $10{\cdot}5\mu$.

Watkins-Pitchford (*loc. cit.*, p. 47) states that the majority of the visible siliceous particles (as detected by means of polarised light) in sections of silicotic lungs vary from 2μ to 12μ in maximum diameter. Larger particles seen by Watkins-Pitchford in his histopathological investigation were found, not in the lung tissue, but in the cavities of bronchioles or alveoli.

The examination of silica particles isolated from this lung tissue (case No. 5) and the examination of silica particles *in situ* in lung tissue from several cases agree in leading to the conclusion that the largest particles which gain access to, and become embedded in, the lung proper have a maximum diameter of about 10μ (=about $\frac{1}{2500}$ inch): but few having a larger diameter (and these up to only 12μ) have been found in the lung.

The accompanying diagram represents the appearance presented by the larger particles of the material isolated from the lung: the 70 per cent. composed of particles with diameter less than 1μ has been omitted in the drawing. The diagram has been constructed to show characteristic shapes and their approximate frequency; it has not been constructed from a single field. It will be observed that a frequently occurring shape is a thin wedge, and particles with a less acutely triangular section are also prevalent. The most common shape, however, among particles of all sizes, is something approaching a sphere.

The line below the diagram represents 10μ on the same scale as the drawing, and the circle represents an average red blood corpuscle (nearly 8μ) on the same scale.



Sketch of larger particles of silica isolated from silicotic lung. × 1,000.

The line represents 10μ.

The circle represents a red blood corpuscle.