THE TREATMENT OF SILICOSIS BY ALUMINUM POWDER*

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THE present communication records the results of a research investigation conducted in the Porcupine Gold Mines in Timmins, Ont.

Soon after silicosis became a compensable disease in Ontario under the Workmen's Compensation Act in 1926, the attention of mine operators and physicians was drawn sharply to the prevalence and importance of this condition in the mining industry. A number of examining centres were established in Northern Ontario by the Workmen's Compensation Board and the yearly x-ray examination of miners was made compulsory.

Although working conditions were soon improved, the mining industry realized that they were confronted by a problem demanding basic research for its final solution. The late Sir Frederick Banting had, for a number of years, been interested in silicosis, and it was upon his suggestion that an experimental investigation was undertaken at the McIntyre-Porcupine Mines, Ltd., Schumacher, Ont., in November, 1932. A preliminary report of this investigation was published in 1937 by Denny, Robson and Irwin[1] and a further report by the same authors[2] in 1939.

Accepting the theory that silica exerts its injurious effect upon animal tissue through a slow transformation into silicic acid in the presence of body fluids, these authors assumed that if the solubility of the silicious material retained in the lung could be sufficiently reduced, the usual fibrotic response would be modified or would not occur. A search was therefore undertaken for some non-toxic compound that would fulfil this purpose. After investigating many substances, Denny and Robson discovered in 1936 that the presence of small amounts of aluminum powder almost completely inhibited the solubility of silicious material *in vitro*. An intensive study of the mechanism involved later showed that the reduction in solubility was due chiefly to a coating of the silica particle with a thin film of a gelatinous hydrated alumina which on drying formed the crystalline alpha aluminum monohydrate boehmite ($Al_2O_3H_2O$). The presence of this adsorbed layer on the surface of the quartz was indicated by staining it with aurin (ammonium salt of aurin tricarboxylic acid) and proved by Germer and Storks[4] by means of electron diffraction patterns.

Inhalation experiments with animals were at once begun, using pure quartz dust with and without aluminum powder. (See original communications). These observers showed that while typical silicosis was produced in about 5 months in the control animals receiving silica dust alone, the addition of 1% aluminum powder to inhaled silica dust completely prevented the occurrence of silicosis, even after exposure had been prolonged up to 22 months. It was further shown that the inhaled aluminum powder should be of a particle size below five microns and that it might be inhaled independently of the silica dust. The aluminum powder employed in these experiments was freshly prepared in a ball-mill charged with small aluminum pellets. These mills were placed in the animal cages and the powder dispersed into the atmosphere of the cage by a steady current of air. The inhalation of large quantities of aluminum powder for prolonged periods produced no harmful effects in the experimental animals.

While it had thus been conclusively shown that small amounts of aluminum powder would protect animals against experimental silicosis, no suggestion was made in the publications of Denny, Robson and Irwin that aluminum might be used as a therapeutic agent in silicosis which was already established. The results of these experiments were so conclusive and the harmlessness of aluminum inhalation so well established by the early summer of 1939 that it was felt advisable by the investigators as well as by Sir Frederick Banting to apply this new discovery to the problem of human silicosis. In the Ontario mining industry, however, silicosis is almost invariably a disease which develops extremely slowly, requiring, on the average, about fifteen years' exposure to silica dust. It was therefore clear that if the inhalation of metallic aluminum were employed merely as a

* A preliminary report of this study was read by Dr. Blaisdell before the Toronto Academy of Medicine, February 25, 1943. Dr. Blaisdell immediately afterwards entered military service and so has been unable to take part in this revised report.

prophylactic measure, many years must elapse before its value as a preventive in human silicosis could be proved. It appeared reasonable, on the other hand, to assume that if aluminum powder given to cases of already established silicosis should prove of any *therapeutic* value, it was highly probable that it would eventually prove to be a highly satisfactory *prophylactic* measure.

The proposal was therefore made that a number of individuals already suffering from silicosis should be selected and treated by the inhalation of aluminum powder in the hope that alleviation of the symptoms of the disease might be demonstrated, or that at least the further development of the disease might be arrested.

We might well, at this point, emphasize the opinion of the original investigators as well as our own that too much emphasis has been placed upon the importance of the radiologically-demonstrable fibrous nodule as the disabling factor in silicosis. The visible nodulation upon which the radiological diagnosis of silicosis depends must be regarded as the end-stage of the fibrotic process and as such, is, as far as is known, an irreversible tissue change upon which no therapeutic agent can conceivably have any effect. We feel, moreover, that discrete fibrous nodulation *per se* in the absence of infection or emphysema does not necessarily produce measurable disability especially in reasonably young individuals. There is, moreover, a preceding or accompanying phase in the development of silicosis characterized by a mild inflammatory thickening of many of the alveolar walls with an infiltration of lymphocytes and alveolar phagocytes laden with minute particles of silica. Irwin has shown by the injection of suspended particles into the skin of a rabbit's ear that histocytes under the influence of the silica which they contain, are gradually transformed into fixed tissue fibroblasts, arrange themselves in concentric whorls, gradually lose their nuclei and finally form the typical hyalinized avascular nodule, characteristic of silicosis. Irwin has also shown that if approximately 1% of metallic aluminum powder is added to the silica suspension before injection, the cells phagocyting both aluminum and silica particles do not show any tendency toward fibroblastic proliferation or nodule formation, the microscopic picture remaining that of a benign foreign-body reaction.

It is therefore assumed that if aluminum powder can be picked up by alveolar phagocytes already containing silica particles or by phagocytes which later ingest silicious material, they will retain the characteristics of normal phagocytic cells. It is quite possible, moreover, and there is some experimental evidence to substantiate the belief, that such phagocytes instead of becoming fixed tissue cells in the formation of a fibrous nodule, are eliminated from the body by the bronchial tree. Thus a large amount of potentially dangerous silica in the lung is eliminated and the mild inflammatory thickening of the alveolar walls, producing nodule formation and decreasing respiratory exchange is lessened. It was also felt that free silica in the lung might have some directly toxic effect other than the production of silicic acid which might be quickly eliminated by the coating action of aluminum. Through one or both of these mechanisms, therefore, it was believed possible that the inhalation of aluminum powder might have a beneficial effect in those with already-established silicosis.

It was the wish of the original investigators as well as of the mine operators that the possible therapeutic value of aluminum powder be investigated by an entirely independent group not formerly associated with this work. The authors of this report had the honour to be chosen in this capacity.

EFFECTS OF INHALING ALUMINUM POWDER

Upon entering upon this investigation we decided to endeavour to determine the effect of the inhalation of aluminum powder in man. In the autumn of 1939 we went to the Pittsburg plant of the Aluminum Company of America. This visit was made possible through the interest and courtesy of Dr. F. C. Frary, Director of Research of that Corporation. We were shown the plant where aluminum powder, used in the manufacture of paint and ink, was made. This powder was prepared by pounding small pieces of thin aluminum sheets into a fine dust. Stamp mills were loaded about every three hours. The powder was collected in the mill and when the stamping was completed (about every three hours) these mills were emptied into a large container in the centre of the room. There was considerable dust in the room at all times but when the pans were emptied it

was extremely dense and, being light, it remained suspended in the air for a long time.

The workmen, at the present time, wear respirators, but this has only been the practice for the past three or four years. There were 125 employees engaged in this work. Their exposure periods ranged from six to twenty-three years, with an average of twelve years. It was obvious that these men had inhaled heavy concentrations of aluminum dust over long periods of time. Dr. J. B. McConnaughy, the physician in charge of these workmen, very kindly reviewed his records with us. The health of these workmen was better than that of the 3,000 others employed in other sections of the large plant of the Aluminum Company in New Kensington. X-ray films of all men had been taken each year for the three years preceding our visit. These radiographs showed no abnormalities which could be attributed to the inhalation of dust. Three, in their early films, showed shadows suggestive of a minimal tuberculous infiltrate which were not evident in the later films. Thus we felt justified in concluding that inhalation of even large amounts of aluminum powder over many years had no harmful effect. It did not cause lung damage nor favour the development of tuberculosis or any other pulmonary condition.

In order that a close clinical and laboratory investigation could be carried out on cases selected for aluminum powder therapy, funds were generously provided by the mines of the Porcupine for the establishment of a centre in Timmins District, Ontario. Suitable quarters were secured in St. Mary's Hospital and a complete unit was organized for the purpose of clinical laboratory examination including respiratory function tests, and also for further experimental work. This centre is known as the Porcupine Clinic for Silicosis Research and has been in operation since January, 1940. Facilities for x-ray examination were provided without charge by the Workmen's Compensation Board to whom we are indebted for this service. Free access to the Compensation Board's records of all silicotics was also provided.

Before treatment with aluminum powder, each subject was put through a definite routine of examination, requiring, in some instances, several days' investigation. A detailed clinical and occupation history was recorded and a complete physical examination was made, with special attention to the pulmonary and cardiovascular systems (D.W.C.). Stereoscopic films were made of the chest as well as flat plates at maximum inspiration and expiration for lung volume measurements. The laboratory investigation included the usual tests such as complete hæmatological examination, urinalysis, sedimentation time, electrocardiogram, tuberculin skin test, Wassermann test, and repeated examination of the sputum for tubercle bacilli by both microscopic and cultural methods. In some cases the basal metabolic rate was determined employing the Haldane-Douglas bag method. Many of these examinations were repeated at frequent intervals during the course of aluminum treatment and were continued until the spring of 1943.

One of the chief problems confronting us was the selection of some method whereby the degree of pulmonary disability or dysfunction could be approximately determined. In recent years a great deal of attention has been devoted to this study both in Europe and America and the choice of methods applicable to the existing conditions was not easy. Our attention, however, was drawn to the extensive investigations of Professor McCann and co-workers at the University of Rochester, Rochester, N.Y. After a careful consideration of these methods, we had the opportunity of visiting Professor McCann's Department on several occasions and of becoming thoroughly familiar with the methods employed. (For a detailed description of this technique the reader is referred to the many papers appearing from Professor McCann's Department over the past number of years).

For our own purpose these tests were modified, but only slightly. Unfortunately, the technique is too complicated for widespread clinical application and requires much special equipment as well as the services of an expert chemist familiar with the technique of gas analysis. In general, however, the tests fall into two groups. The first of these is the measurement of total lung volume and a calculation of the ratios of the various pulmonary subdivisions such as reserve and residual air, complemental air and vital capacity, with a correlation of mathematically predicted values based upon x-ray measurements of the chest. These tests involve the use of several spirometers and the Van Slyke manometric apparatus for the determination of residual air by the modified Christie method which we employed. These tests are carried out with the patient at rest.

The second and more useful group of tests constitutes a study of pulmonary ventilation before, during and following a standard exercise test with a measure of minute to minute ventilation, correlated with respiratory rate, tidal volume and with maximum minute ventilation. For the standard exercise tests a specially con-

structed electrodynamic brake bicycle ergometer, modified from the description of Kelso and Hellebrandt[3] was employed. The expired air was collected in Douglas bags on a special wooden rack, a system of values permitting minute by minute samples in separate bags. The volume of air collected in the bags was measured in a 100-litre Tissot spirometer. Part of the equipment including the ergometer, Douglas bags and spirometer, is illustrated in Fig. 1. Maximum minute ventilation was measured by having the subject breathe forcibly and with maximum effort into the Tissot spirometer for 30 seconds and multiplying the volume of air collected by 2.

Selection of cases.—The first problem in this study was the selection of subjects suitable for treatment. It was decided that the following qualifications should be met: (1) All those treated should be acknowledged as suffering from silicosis (with or without disability) by the Workmen's Compensation Board of Ontario. (2) They must have sufficient knowledge of English to understand what was being done and be co-operative. (3) They must volunteer to undergo the various tests and subsequent treatment. (4) They should not be over 55 years of age. (5) They should have worked at least five years underground and should not have been removed from dust exposure more than two years. (6) They must be in good general condition and free from such complications as tuberculosis, severe emphysema, syphilis, renal and cardio-vascular disease. (7) Those with a definite disability resulting from silicosis were to be preferred.

Upon studying the situation in Timmins many difficulties were encountered in the selection of suitable cases. Among the miners in the Porcupine area there were 360 silicotics. From a study of case histories and x-rays alone it was found that only about 150 were at all suitable. The reasons for rejection were age, complicating diseases—chiefly tuberculous or non-pulmonary conditions, or because too long a time had elapsed since exposure to dust. Some refused tests and treatment.

Eventually 102 were examined. Treatment was begun in 41. For various reasons 7 took only a few treatments, leaving 34 who completed the desired course. A somewhat more detailed description of the 34 treated cases will show that it was impossible to select many cases which met all the qualifications originally proposed. They were all acknowledged silicotics with the characteristic radiographs but 18 of them showed little or no disability. All were working at their usual occupations. Eight had complicating conditions—2 peptic ulcer, 2 emphysema, 1 hypertension, 1 Reynaud's disease, 1 bundle branch block, 5 were between the age of 50 and 55, 2 renal calculi, 2 were in poor general condition. Only 3 showed a definitely measurable disability due to silicosis alone and were otherwise suitable, but even in these the disability was not marked.

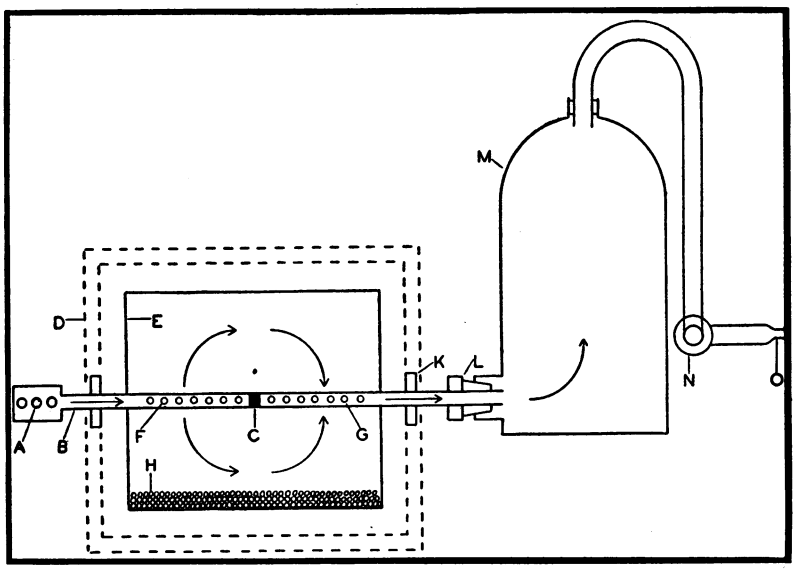


Fig. 1

Thus it would appear that in the Porcupine Gold Mines silicosis of itself did not produce great disability.

Silicosis shortens working life because it is accompanied by emphysema and it opens the door to pulmonary complications, both tuberculous and non-tuberculous. A silicotic who is fortunate enough to escape complicating diseases begins, after about 15 to 18 years, to suffer from the effects of gradually increasing emphysema by which the lung endeavours to compensate for the silicotic fibrosis. The resultant disability is slowly progressive and does not reach a high degree for several years or until some added pulmonary disease occurs. These facts made it difficult to evaluate the effect of aluminum therapy in that in some of the cases complications were already present and in the uncomplicated cases the disability was slight.

All tests of respiratory function were carried out in the morning after the subject had had a satisfactory night's rest. On arriving at the clinic he rested about

30 minutes before beginning the tests. As described above, the determination of lung volumes was first undertaken. Mid capacity (reserve air plus residual air) was measured by Christie's method of oxygen dilution without forced breathing. A special 7-litre spirometer, somewhat similar to the Benedict-Roth type and equipped with a motor blower, was filled with an accurately measured amount of oxygen. At the end of a normal expiration the subject was connected with the spirometer and breathed pure oxygen for a period of 7 minutes, the expired air being conducted through a canister of soda lime placed outside the spirometer.

Respiration and oxygen consumption were recorded on a slowly-moving kymograph drum. At the end of 7 minutes the subject was disconnected and a sample of the gas mixture remaining in the spirometer was withdrawn by means of a special mercury sampling tube. The whole procedure was then repeated. The nitrogen content of these samples was (later) determined in duplicate with the Van Slyke manometric apparatus and the mid-capacity (reserve air plus residual air) calculated by Christie's formula. The complemental (supplementary) air and reserve air were measured on the same spirometer. The latter was then subtracted from the mid-capacity (as determined above) this value representing the residual air. The vital capacity was measured by a Collins vitalometer with the subject both lying down and in the sitting position. After the above values had been determined, the following ratios were calculated:

$$\frac{\text{Vital Capacity}}{\text{Total Capacity}} \times 100 \text{ (normal 70\% or over)}$$

$$\frac{\text{Residual Air}}{\text{Total Capacity}} \times 100 \text{ (normal not over 25\%)}$$

$$\frac{\text{Mid Capacity}}{\text{Total Capacity}} \times 100 \text{ (normal not over 40\%)}$$

After a short period of rest the subject mounted the bicycle ergometer (Fig. 4) and was connected with a Douglas bag through a system of two Bailey valves. The expired air was collected in this manner during a 7-minute period of rest, an electrical counter recording respiratory rate. After this resting period the subject was required to pedal the bicycle at a rate representing 300 kilogram-meters of work per minute for a 5-minute period. The expired air was collected in separate Douglas bags during each minute of exercise and the respiratory rate recorded minute by minute. At the end of the exercise period the expired air was collected for a three-minute period of rest in another bag, the respiratory rate again being recorded for each minute.

The subject was then rested for a period of about 30 minutes and repeated the exercise test, on this occasion, however, performing 600 kilogram-meters of work per minute for 5 minutes. The expired air was collected and the respiratory rate recorded as above both during exercise and for the 3 minutes' rest immediately following exercise.

After a further period of rest the maximum minute ventilation was measured as previously described. It was found that considerable practice was required before our subjects carried out this test in a satisfactory manner.

In recording the above tests, the respiratory rate and tidal volume were plotted graphically for the resting period before exercise (7 minutes) for each minute during exercise (5 minutes) and for the rest period following exercise (3 minutes). Such a graph in itself is a rather useful index of respiratory function. When the normal subject, at moderate exercise, must increase the amount of air breathed in a given unit of time, he does so *chiefly* by increasing his tidal volume (depth of each inspiration) with only slight rise in respiratory rate. In the case of pulmonary fibrosis, however, there is difficulty in increasing the tidal volume sufficiently to provide the required ventilation. As the depth of each inspiration becomes more and more limited by increasing fibrosis, it becomes necessary to accelerate the respiratory rate during exercise. In normal subjects at 600 Kg/M of work per minute, the respiratory rate rises only slightly, showing an almost straight line when recorded graphically and there is a compensatory rise in tidal volume to 1,500 c.c. or more. In cases of pulmonary disability, however, under the same exercise the tidal volume tends to remain relatively low with a steep rise in the respiratory rate to 40 or 50 per minute.

From the above ventilation studies the following were recorded:

1. Total ventilation at exercise,
2. Total ventilation at exercise and rest,
3. Maximum minute ventilation,
4. Ventilation index (total ventilation/vital capacity),
5. $\frac{\text{Minute ventilation at rest}}{\text{Maximum minute ventilation}}$,
6. $\frac{\text{Minute ventilation at exercise}}{\text{Maximum minute ventilation}}$.

The above will serve as a brief outline of the manner in which our subjects were investigated before, during and following aluminum powder therapy. Each subject was tested in the manner described at least twice and in some instances three times before treatment was begun. During the period under treatment the tests were repeated at intervals averaging about every three months. Following treatment less frequent tests were done. The value of the above procedures is discussed later.

It was shown by the original investigators (Denny, Robson and Irwin) that to be effective the metallic aluminum powder must be of a particle size comparable to that of the dangerous silica particle, *i.e.*, under 5 microns in diameter. For the ease of administration it was decided both in animal experiments and in the treatment of human subjects to manufacture the powder directly before inhalation and to administer it while it was still suspended in the atmosphere in its original finely-divided state. In the treatment of human silicosis, a mill of the type illustrated in Figs. 1 and 2 was employed.

Essentially it consists of an aluminum cylinder or drum 12 x 12 inches mounted on a ¾ inch hollow shaft. This shaft, inside the mill, has a large number of small perforations on either side of a short, central peng or core which prevents the inspired air from being drawn directly through the shaft without entering the cylinder. The latter is enclosed in a wooden box lined with sound-absorbing material to reduce the noise of grinding. The shaft is connected by means of a perforated cam to a 20 to 1 reducing gear operated by a ¼ H.P. electric motor, rotating the drum or cylinder at approximately 80 R.P.M. All operating parts were well grounded. The opposite end of the hollow shaft is connected with a 12-litre glass bottle which serves as a settling or sedimenting chamber (see Fig. 3) where the coarser particles of powder settle out.

A charge of 25 pounds of chemically pure aluminum pellets (sheared from 3/16 inch aluminum rod and measuring about 3/16 in length) is placed in the drum, one end of which is removable for this purpose. A small amount of aluminum powder is also introduced with the pellets as a "primer" to facilitate the grinding process in a new mill. Before use, the mill should be operated for several hours daily for a few days until maximum efficiency is reached. Such mills will vary slightly in efficiency but in general it may be stated that, at an airflow rate of 10 litres per minute through the mill about 2 to 3 milligrams of aluminum powder per litre of air are produced. This powder is black in colour, having the appearance of soot or lamp-black and assays 20% metallic aluminum and 80% oxide.

TREATMENT WITH ALUMINUM POWDER

In actual operation the mill is run for about twenty minutes each day before a treatment is given. During this time 10 litres of air per minute are drawn through the mill, employing a vacuum or water pump and the powder collected on a cotton filter which is removed occasionally and discarded. After this warming up period the patient is connected to the 12-litre bottle (see Fig. 3) by a 1-inch rubber tube. A double Douglas valve prevents rebreathing into the system, the patient being connected to the valve by a short piece of rubber tubing and a metal mouthpiece. The nose is clamped lightly. As the subject inspires, air enters the shaft through the perforations in the cam, and is drawn into the interior of the cylinder through the small perforations in the shaft. Here the air becomes charged with powder and is drawn back into the shaft through the perforations on the other side of the centre peng. The powder-laden air enters the bottom of the 12-litre bottle where the coarser particles settle out, the finer particles only entering the outlet tube at the top of the bottle to which the subject is connected.

Treatments were begun with a 5-minute inhalation daily. This was increased by 5 minutes every few days until at the end of about a month the patient was receiving 30-minute periods daily. Such treatments were continued six days weekly until a total of about 200 treatments had been administered. A few of our cases had as many as 300. The latter is probably much more than actually required and in the latter part of the investigation we tended to reduce the number of treatments.

The actual effective dosage of aluminum powder administered by this or any other inhalation method is difficult if not impossible to determine. A large proportion of the powder is arrested in the mouth and in the upper respiratory passages. It also is likely that most of the dust reaching even the smaller bronchi is rapidly excreted. To be effective, dust probably must reach the terminal bronchioles or alveoli and be retained for some considerable period of time. This period obviously must be of sufficient length to permit the coating action upon the silica particle to occur. The exact length of time required for this reaction in the lung is not known. It is 4 to 5 hours *in vitro*.

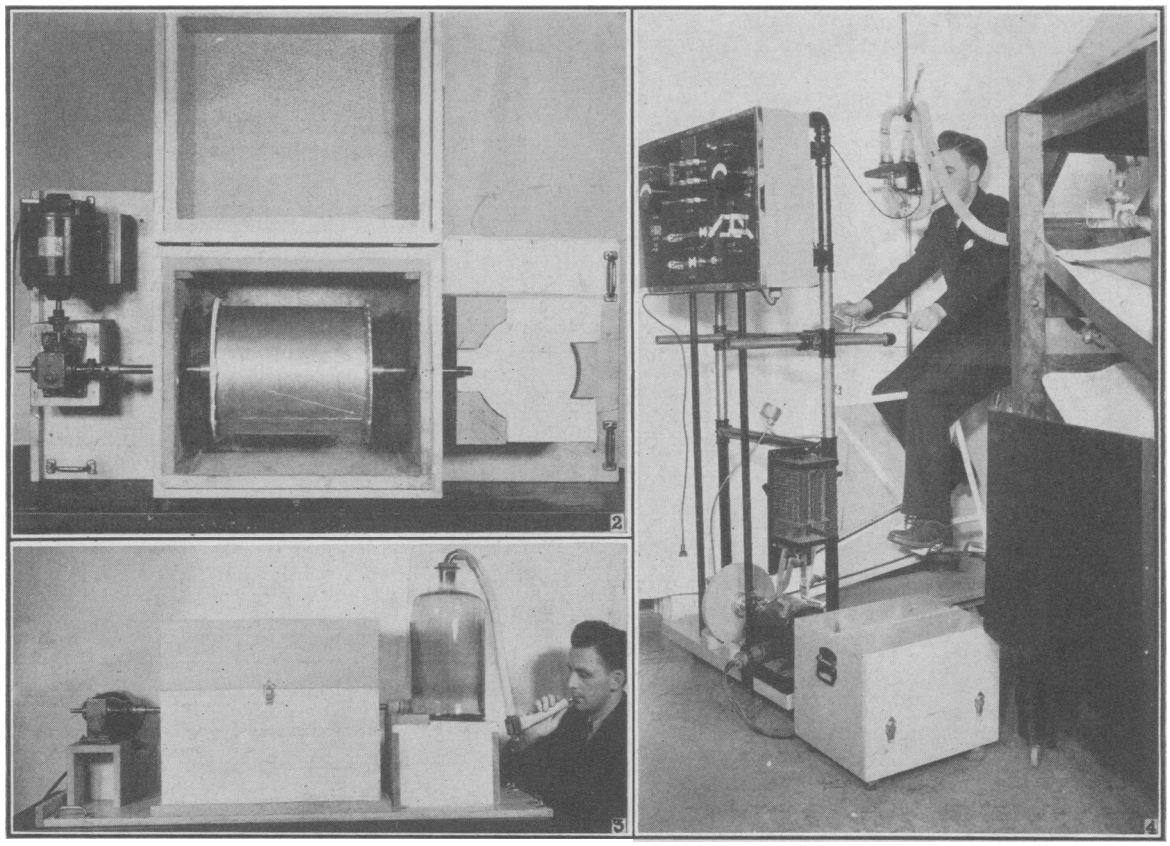
Experimenting with rabbits exposed to an atmosphere containing a known and constant concentration of aluminum powder, Irwin demonstrated by chemical assay of the lungs that the amount permanently retained over a period of several months was from 2 to 7%. How far these findings can be applied to the human subject is, of course, purely conjectural. It is probable, moreover, that as in the case of silica dust, the amount of aluminum powder permanently retained must vary enormously in different individuals. Assuming, however, that a subject breathing 8 litres per minute from a mill delivering 2 mgm. per litre of which 2/3 is arrested by the inhalator valve receives 200 treatments of 30 minutes each and retains 5% of the inhaled dust, the amount of dust retained would be:

$$\frac{5}{100} \times \frac{8 \text{ litres} \times 2 \text{ mgm. per litre} \times 30 \text{ minutes} \times 200 \text{ treatments}}{1{,}000 \text{ mgm.}} \times \frac{1}{3} = 1.6 \text{ gm.}$$

The inhalation of aluminum powder in the manner above described occasions no discomfort or distress. The inhaled powder is quite invisible, odourless and tasteless. Apart from slight dryness of the mouth no subjective symptoms are experienced during inhalation. Immediately following treatment a variable

amount of black powder is seen on the tongue and upon the laryngeal and pharyngeal mucous membrane. Sputum, if present, shows the presence of decreasing amounts of black dust for several hours following treatment. If the subject contracted a severe cold, as occasionally happened, treatment was stopped for a few days.

Throughout this investigation we enjoyed the fullest co-operation of our subjects. Only in a few instances did a man fail to complete the prescribed course of treatment. The great majority felt that they were deriving definite benefit from this form of therapy and were willing to continue it as long as requested.



MEASUREMENT OF PULMONARY DISABILITY

The methods employed for the measurement of pulmonary disability have been described briefly. Several hundred complete tests were carried out both on subjects under treatment and upon a control group. Some of the former were tested from ten to twenty times. It was felt in the early part of the investigation that the methods of determining disability would prove most useful. Later, however, they appeared to be somewhat disappointing considering the amount of time required and the effort involved in carrying them out. Space does not permit a detailed criticism of these methods but a few general comments may not be out of place.

In the publications of the Rochester group it was stated that the ratio of residual air to total pulmonary capacity (RA/TC) could be used as an index of pulmonary disability. This ratio should not be above 25 in the normal individual and that as disability progressed this value proportionately increased. The same group, employing exercise tests, stated that the ventilation index (total ventilation/vital capacity) was also a useful measure of pulmonary dysfunction. There should, therefore, be a reasonably close relationship between the degree of disability determined by each method.

After carrying out a large number of tests we attempted to correlate the degree of dysfunction indicated by the first test (RA/TC) with that shown by the other (ventilation index). Much to our surprise it was found that little if any correlation existed between the two tests except in three cases of extreme disability

(see Fig. 5). Many of our cases showing a high (RA/TC) ratio showed an approximately normal ventilation index on exercise. On the other hand, a number of our subjects whose ventilation index was high (indicating disability) had little or no increase in residual air and showed a RA/TC ratio within normal limits. As far as we know, this discrepancy has not been shown before and constitutes a serious criticism of this method of testing. It has been our experience that the exercise tests are a much more valuable and less time-consuming procedure than the estimation of lung volume and pulmonary ratios. We have been unable to confirm the observation of McCann and his co-workers that an increase in residual air is *necessarily* an indication of present respiratory disability. While it is true that many cases of obvious disability do show this increase, we have recorded the same finding in a number of cases in whom there was no other indication of pulmonary dysfunction. These were miners engaging in heavy physical labour underground.

We therefore regard an increase in residual air as an indication of some alteration in lung structure or function which may, but does not necessarily reflect itself in significant respiratory disability. The lung, like any other organ, has a tremendous reserve and undoubtedly can suffer alteration or even considerable damage before actual respiratory insufficiency occurs.

CORRELATION OF DEGREE OF DISABILITY BETWEEN RA/TC AND VENTILATION INDEX AT 600 Kgm.

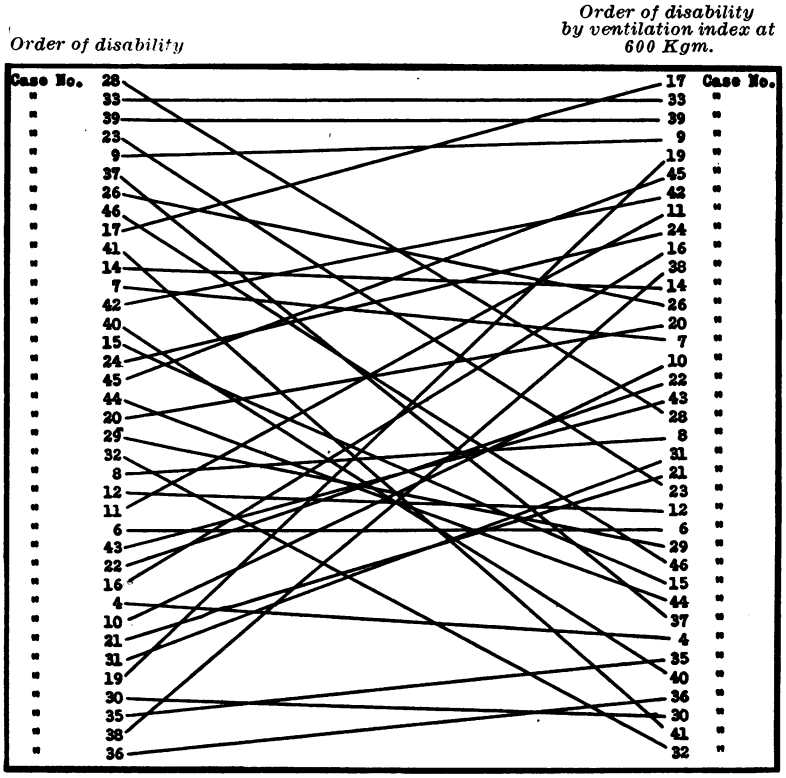


Fig. 5

During our investigation the fact has been repeatedly called to our attention that there is no close or definite relationship between the degree of pulmonary fibrosis visualized radiographically and the extent of disability. It is not uncommon to find an individual with most extensive fibrosis and nodulation, carrying on heavy underground work without any symptoms whatever and discharging his duties to the complete satisfaction of his employers.

X-ray studies of the silicotic lung merely indicate the extent of the fibrotic process, give little evidence of the functional capacity of remaining lung structure *and give little or no indication of the presence or degree of respiratory disability.* In a similar manner, the amount of residual air or its relation to total lung volume, cannot be relied upon as an index of existing disability. On the other hand, reflecting as it does an alteration in lung structure, it is probably of definite prognostic value. It is our feeling that a person with increased residual air will in all probability develop disability much sooner than an individual in whom a normal value is found.

In carrying out the exercise tests previously described we also encountered considerable individual variation in a number of our subjects which was difficult to interpret. We felt, however, that the response to exercise was a much more reliable indication of disability than lung volume studies. These tests involve subjecting the individual to a definite strain and when interpreted in the light of considerable experience and in a rather broad manner, give an approximate measurement of lung function. While less time-consuming, they require much

special equipment and could not be readily applied in the ordinary clinic.

RESULTS OF TREATMENT

For the purpose of estimating the result of treatment these cases will be divided into three groups—Group 1, those showing definite improvement (7); Group 2, slight improvement (12); Group 3, no improvement (15).

The average age by groups was as follows:

Group 1	44.1
Group 2	45.5
Group 3	43.7

The extremes being 33 and 57.

The average years' exposure to dust was:

Group 1	18.6
Group 2	18.4
Group 3	19.3

There were then no significant differences in age or exposure to dust in the three groups. The symptoms before and after treatment are presented by groups.

Dyspnœa on exertion was the most prominent and constant symptom. It is here divided into severe, moderate and slight as brought out by the man's history and response to a definite amount of exercise.

DYSPNŒA — GROUP 1 (7 MEN)

	Severe	*Moderate*	*Slight*	*None*
Before	1	4	2	0
After	0	0	3	4

That is, before treatment all complained of some degree of dyspnœa and after treatment only three suffered slightly therefrom.

GROUP 2 (12 MEN)

	Severe	*Moderate*	*Slight*	*None*
Before	0	5	6	1
After	0	0	6	6

GROUP 3 (15 MEN)

	Severe	*Moderate*	*Slight*	*None*
Before	0	7	5	2
After	0	5	7	2

It is noteworthy that in all groups some individuals showed improvement and none was worse.

Fatigue ran parallel to dyspnœa and was equally prominent in all groups. The evaluation of this symptom is admittedly difficult and probably open to criticism but the picture follows so closely that of dyspnœa that it is thought advisable to present it.

GROUP 1

	Severe	*Moderate*	*Slight*	*None*
Before	1	4	2	0
After	0	0	3	4

GROUP 2

	Severe	*Moderate*	*Slight*	*None*
Before	0	5	5	2
After	0	0	5	7

GROUP 3

	Severe	*Moderate*	*Slight*	*None*
Before	0	4	8	2
After	0	3	8	3

Cough and expectoration were not the cause of much complaint except in one case in group 3, who had fairly marked emphysema. He was not benefited by treatment.

GROUP 1

	Moderate	*Slight*	*None*
Before	4	2	1
After	0	3	4

GROUP 2

	Moderate	*Slight*	*None*
Before	2	2	8
After	0	3	9

GROUP 3

	Severe	*Moderate*	*Slight*	*None*
Before	1	0	6	7
After	1	0	5	8

Pain was in no case severe. It was described as an aching or burning or feeling of tightness in the chest. The locations were in order of frequency—substernal, below the angle of the scapula, low in the axilla. In all groups there was less chest discomfort after treatment.

GROUP 1

	Moderate	*Slight*	*None*
Before	1	1	5
After	0	1	6

GROUP 2

	Moderate	*Slight*	*None*
Before	1	5	6
After	0	1	11

GROUP 3

	Moderate	*Slight*	*None*
Before	0	6	8
After	0	4	10

A gain in weight was most evidenced in Group 1 where five of the seven gained an average of 8 lb. (extremes 5 to 20 lb.). In Group 2 only three gained but one of these who gained 10 lb. should be disregarded because he was

successfully treated for duodenal ulcer while taking aluminum. The gain in weight in this case can be attributed to improved digestion. In Group 3 none gained nor lost.

Physical signs showed little change. Two of the men in Group 1 and one in Group 3 had widespread bilateral moisture which almost entirely cleared under treatment. Chest measurements, such as anterio-posterior diameter and expansion, remained unchanged.

Radiographs taken at frequent intervals before, during, and after treatment, showed no appreciable change. This emphasizes what we have pointed out above, that the x-ray picture gives little or no indication of the degree of functional disability.

Functional tests during and following treatment showed definite improvement (on exercise) in 5, 14.7%; slight or questionable improvement in 7, 20.5% (exercise 3, lung volume 3, both 1) 22 unchanged. None was worse.

Our observations of silicosis in these Porcupine gold miners showed that disability develops very slowly. Minute amounts of silicic acid, formed by the interaction of quartz and the body fluids, interferes with phagocytosis (dust removal) and causes fibrosis. As fibrosis increases it lessens the elasticity of the lung, impedes the circulation of blood and lymph, and results in the development of compensatory emphysema. With fibrosis and emphysema once established the lung is permanently damaged.

Furthermore, we believe that throughout the period of dust exposure, and for some time thereafter, the lung parenchyma is the seat of a low-grade inflammatory process which reduces lung elasticity and interferes with the exchange of gases and predisposes to fibrosis. If the formation of silicic acid can be reduced or entirely eliminated amelioration of symptoms can be expected. It would seem highly probable that it is this mechanism which explains the improvement in our treated cases, 34 of whom had what we considered a sufficient number of treatments (over 100). Seven (20%) of these showed very definite clinical improvement; less marked amelioration of symptoms was found in twelve (35%); the other 15 (45%) remained stationary over a period of three and one-half years. None was worse in spite of continual employment in quartz dust during the whole period of observation.

We had originally hoped to divide our cases into two equal groups, retaining one group as a control. The difficulties of selection have been described which resulted in our control group being reduced to nine men who worked and were tested repeatedly under the same conditions as the treated group over a period of three years. Six (66%) were worse; two (22%) were unchanged; one (12%) was better.

We are of the opinion that all silicotics, without tuberculosis, should be given sixty to one hundred treatments at tri-weekly intervals of the type and in the manner herein described with the expectation that 50% will show amelioration of symptoms with possible increase in working capacity. It is probable that the silicotic process will be arrested and will remain so with additional brief yearly or bi-yearly treatments.

Our observations during this study have convinced us that the inhalation of aluminum powder, as herein described, is quite harmless. This is supported by our observations in the plant of the Aluminum Company of America in Pittsburg, described earlier in this article, and by the fact that 34 men each received from 100 to 300 treatments with no harmful effects.

In view of the fact that most of the pulmonary damage resulting from silicosis is irreversible, the great field of this treatment is prophylactic, as originally claimed by Denny, Robson and Irwin. We would recommend that those exposed to silicious dust should receive prophylactic inhalations of aluminum powder. It is our opinion that no harm would result from this procedure and that the development of silicosis would probably be prevented.

SUMMARY

This investigation, which has now been in progress for a period of three years, is based upon the experimental work of Denny, Robson, and Irwin, who showed that the development of silicosis in animals could be prevented by the inhalation of small quantities of metallic aluminum powder. Following the publication of their observations in 1939, the treatment of human cases of silicosis was proposed in the hope that aluminum powder might act as a therapeutic agent in already established cases of this disease. A clinic was established at Timmins, Ont., where a large number of silicotic subjects could be observed.

In the selection of cases to be treated, only men who were still exposed to silica dust and were still employed in the mines were considered, and only those with uncomplicated silicosis with measurable pulmonary disability were chosen.

Before treatment was instituted, each individual was carefully studied clinically and radiographically, and a large number of respiratory function tests were carried out. The latter included a study of total lung volume and pulmonary ratios as described by McCann and his co-workers. Pulmonary ventilation studies were also made, employing standard exercise tests on a calibrated bicycle ergometer.

Selected cases were treated by the daily inhalation of fine aluminum powder, freshly ground from small aluminum pellets in a specially-constructed mill. A number of these powder mills were employed at various mines and treatment was usually given just before or following a shift. Treatment, administered daily, was begun by 5 minutes' inhalation through the powder mill. This period was gradually increased to 30 minutes daily, and was continued over periods in some cases of almost a year, a small number of men receiving approximately 300 treatments, the majority, however, receiving about 200. About 50 patients have received this form of therapy, 34 of whom have completed the course prescribed.

Results of Treatment

This investigation has shown conclusively that the administration of aluminum powder in the manner described is entirely harmless and has proved definitely beneficial in a number of cases under our observation. Out of 34 cases studied, 19, or 55%, have shown clinical improvement, apparent chiefly in the lessening or disappearance of shortness of breath, cough, pain in the chest, and fatigue. A reduction in the incidence of colds and a gain in weight have also been observed in many of the cases. While 15 cases have remained stationary, it must be emphasized that they are no worse and their condition has not progressed, in spite of continuous employment in silica dust during the period of our investigation.

Respiratory function tests, repeated at intervals of about every three months, have shown improvement in 12 or about one-third of the treated cases. While 22 remained stationary, they are no worse in spite of continued exposure to silica dust. A group of controls, untreated by aluminum, have shown progression of their disease in 66% of nine cases while under observation.

Aluminum dust cannot be regarded in any sense as a "cure" for silicosis insofar as restoring to normal lung tissue which has already undergone fibrotic change is concerned. Its use, however, would appear to be followed by beneficial results in a significant proportion of cases, chiefly in the amelioration of symptoms and in the increased capacity to work. In view of these findings and the experimental work of Denny, Robson and Irwin, we believe the inhalation of finely particulate aluminum powder offers every prospect of preventing the development of human silicosis.

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HYPERTENSION AFTER REMOVAL OF A RENAL CALCULUS

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SINCE Goldblatt[1] produced experimental hypertension in animals by compression of the renal arteries, numerous clinical cases of hypertension have been reported cured or improved by nephrectomy. Abeshouse[2] has recently reviewed the extensive literature regarding unilateral kidney disease and hypertension. Braasch *et al.*[3] found, however, no greater incidence of hypertension among their patients admitted to hospital for renal surgery than in a random control group; and since there are many reports of lowering of the elevated blood pressure by bed rest, removal of anxiety, and various surgical procedures, it seems doubtful if all the reported cures after nephrectomy are due to the nephrectomy.