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# PULMONARY FUNCTION STUDIES

# IN MEN EXPOSED FOR TEN OR MORE YEARS TO

# INHALATION OF ASBESTOS FIBRES

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Seventy-four men were subjects for this study, fifty-seven of whom had been, in the course of their daily work, exposed to an atmosphere containing airborne asbestos fibres in varying concentrations. The remaining seventeen men had no exposure to asbestos fibre other than that which might possibly occur to anyone living in their community. The purpose of this study was to learn what the physiological abnormalities are in persons with various degrees of pulmonary x-ray abnormalities and with various degrees of intensity of exposure to airborne asbestos fibre. It should be clearly understood that this study was not designed to disclose the proportion of men working in the asbestos industry who might have roentgenographic or physiologic abnormalities.

Now we can go to definitions.

How can one define and quantitate the various degrees of exposure to the inhalation of asbestos fibres? The thing to start with was the duration of exposure, as obtained from the subject and from the company. We arbitrarily assigned a value of two units for each year of exposure.

The various jobs at which the men worked were grouped in four categories on the basis of the intensity of exposure. This classification was arrived at after conference with the industrial engineers and plant physicians.

The men working underground or as loaders, drillers wet or in shipping shed, the primary crushers and dryers received one unit for their exposure.

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The secondary crushers, the men working in dry rock storage or as dry drilling and grizzly were assigned three units. Floor men, screen men, millwright, tester, grader and cobber were assigned six units. The mill shipper, the bagger and the sewer were assigned nine units. Example:

A subject who spent 10 years as bagger had 10 x 2 x 9 = 180 units and 10 years as millwright had 10 x 2 x 6 = 120 units or a total of 300 units for 20 years of employment.

As far as the x-ray classification is concerned, we divided the cases in four groups on the basis of the degree by which they were abnormal.

We called the normal x-ray pattern 0. $P^1$ designated those who showed a slight exaggeration of linear markings. $P^2$ indicated a marked increase of the linear markings. $P^{2+}$ categorized a haziness or ground glass appearance in the middle and basal fields of the lungs. This category in general embraced those films considered characteristic of clinical asbestosis.

It is difficult in asbestosis to be consistent with oneself in re-reading the films and still more difficult to agree with one another on each film. For this reason, each film was read twice by six different physicians--two radiologists, two plant physicians and two other clinicians. That made a total of 12 readings in each case. Usually there was no disagreement on extremes. The difficulty resided in the border line cases between $P^2$ and $P^{2+}$. These few cases were studied again until a final agreement was reached and where not, the weight of the decision was given to the radiologists.

In essence, we have attempted to rank the cases in respect to the degree to which the roentgenogram departs from normal.

Each person was thoroughly studied from the clinical standpoint as well as being subjected to the physiological measurements reported in the remainder of the discussion.

What are the abnormal physiological findings on a case who fits x-ray and clinical criteria of asbestosis?

The following patient is a good example of it.

Mr. W. F., 55 years old, had spent 20 years as bagger, 6 years in the mill and 8 years on surface where there was no dust. That gave him a figure of 430 units for duration X intensity of exposure. The x-ray that you see (Fig. 1) is quite characteristic of advanced asbestosis and this subject was unanimously called $P^{2+}$. For the last 16 years he was a chronic cougher, specially in winter, but expectorated little. He also complained of exertional dyspnea for the last 7 or 8 years.

The physiological data on him are as follows:

| | Det. | Pred. |
|---|---|---|
| M. B. C. | 115 L/min. | 128 L/min. |
| LUNG VOLUME | Det. | Pred. |
| T. Vol. | 4.28 L. | 5.38 L. |
| V. C. | 2.84 | 4.06 |
| F.R.C. | 2.05 | 2.01 |
| Resp. Res. | 0.61 | 0.69 |
| Resid. C. | 1.44 | 1.32 |

**ARTERIAL BLOOD AT EXERCISE:** 3 mph. 4% grade 6 minutes

| | |
|---|---|
| $O_2$ Cons./$M_2$/cc. | 635 cc. |
| $O_2$ Content | 15.94 Vol.% |
| $O_2$ Capacity | 20.70 Vol.% |
| % Saturation | 76 % |
| Alv. $pO_2$ | 105 mm.Hg |
| Art. $pO_2$ | 39 mm.Hg |
| A.A. Diff. | 66 mm.Hg |
| $O_2V$ | 37 L. |

**MAXIMUM EXERCISE:** 3 mph. 8% 6 minutes

| | |
|---|---|
| Min. Vent. at 37° | 60.9 L/min. |
| $O_2$ Cons./$M_2$ | 775 cc. |
| $O_2V$ | 43.4 L. |
| R. Q. | 1.03 |
| M.V./MBC | 0.54 |
| Resp. Rate (6th min.) | 40/min. |
| Pulse Rate (6th min.) | 168/min. |

The Maximum Breathing Capacity is 115 L/min. versus 128 L/min. predicted.

The Lung Volume showed a diminution of total volume. This is due to a great diminution of the vital capacity that is only 2.84 L. instead of 4.06 L. or 70% of the predicted values. The absolute figure for residual air is only slightly increased but in % over total volume it is increased to 34%. This figure alone,

however, cannot be considered abnormal since we have some subjects his age who were considered as normal and who showed the same percentage.

The data on the Arterial Blood during an exercise at 4% grade and 3 mph. are abnormal. The % saturation of hemoglobin is markedly subnormal during exercise. The alv. $pO_2$ in mm.Hg was absolutely normal at 105 mm.Hg. The art. $pO_2$ in mm.Hg was abnormally low at 30 mm.Hg compared to a mean normal of 82.5 with a S.D. of 5.41. The A.A. difference was 66 mm.Hg when the highest difference in normal persons at exercise is 27 mm.Hg.

At Maximum Exercise, 3 mph. and 8% grade, this patient hyperventilated considerably as can be seen from the high $O_2$v. His $O_2$ consumption/$M_2$/min. attained only 775 cc. instead of 1285 as predicted for a normal man his age.

To summarize, the physiological abnormalities reside almost only in a diminution of the total volume of the lung, the unsaturation of the arterial blood at exercise, an increase of the A.A. difference due to a drop of arterial $pO_2$ and in the inability to perform as well as normals on the treadmill with hyperventilation.

Is it possible that one can get the typical x-ray changes of asbestosis,without the pnysiological abnormalities just seen, after a long time of exposure in a very dusty place?

Mr. D. L., 48 years old, is such a case. This subject worked one year as shipper, 20 years as bagger and two years as granite picker. This gave him a total of 366 units for duration X exposure. He was classified as $P^{2+}$ (Fig. 2) and complained of

cough and slight exertional shortness of breath.

The Maximum Breathing Capacity was 71% of predicted or 100 L/min. instead of 140 L/min. Everybody who has less than 66% of predicted values is considered as abnormal because the S.D. of normals is 17%.

The Lung Volume was in normal limits, his total volume being 111% of the prediction and the residual air 28% of the total lung volume.

ARTERIAL BLOOD AT EXERCISE: 3.5 mph. 8% grade 6 minutes

| | |
|---|---|
| $O_2$ Cons./$M_2$/cc. | 910 cc. |
| $O_2$ Content | 19.86 Vol.% |
| $O_2$ Capacity | 20.58 Vol.% |
| % Saturation | 96.5 % |
| Alv. $pO_2$ | 98 mm.Hg |
| Art. $pO_2$ | 78 mm.Hg |
| A.A. Diff. | 20 mm.Hg |
| $O_2V$ | 26.9 L. |

As we can see, the saturation is perfectly normal and also the A.A. difference.

MAXIMUM EXERCISE: 3.5 mph. 12% grade 6 minutes

| | |
|---|---|
| Min. Vent. at 37° | 73 L/min. |
| $O_2$ Cons./$M_2$ | 1370 cc. |
| $O_2V$ | 31.4 L. |
| R. Q. | 1.04 |
| M.V./MBC | 0.73 |
| Resp. Rate (6th min.) | 56/min. |
| Pulse Rate (6th min.) | 168/min. |

As you can see, all data are in normal limits. The $O_2$ consumed/$M_2$ is even slightly greater than the predicted value for a normal man.

The question may next be asked, "Do physiologic abnormalities develop only after x-ray abnormalities are present?"

The next case illustrates the fact that in some instances there are physiological abnormalities in the absence of clear cut x-ray changes (Fig. 3).

Mr. A. S., 48 years old, worked as railway storekeeper from 1920 to 1935. From 1935 to 1948 he worked as fibre foreman in mills where the concentration of dust was considered as moderate, and the dust of a fine character. He received a total of 168 units for duration X intensity of exposure. The patient's only complaint was occasional head colds.

| | Det. | Pred. |
|---|---|---|
| M. B. C. | 137 L/min. | 141 L/min. |

| LUNG VOLUME | Det. | Pred. |
|---|---|---|
| T. Vol. | 5.38 L. | 5.28 L. |
| V. C. | 3.38 | 4.03 |
| F.R.C. | 2.53 | 1.98 |
| Resp. Res. | 0.53 | 0.73 |
| Resid. C. | 2.00 | 1.25 |
| % Resid. | 37% | 24.8% |

ARTERIAL BLOOD AT EXERCISE: 3.5 mph. 8% grade 6 minutes

| | |
|---|---|
| $O_2$ Cons./$M_2$/cc. | 1100 cc. |
| $O_2$ Content | 18.67 Vol.% |
| $O_2$ Capacity | 20.87 Vol.% |
| % Saturation | 87.5 % |
| Alv. $pO_2$ | 93 mm.Hg |
| Art. $pO_2$ | 63 mm.Hg |
| A.A. Diff. | 30 mm.Hg |
| $O_2V$ | 26.5 L. |
| R. Q. | .96 |

MAXIMUM EXERCISE: 3.5 mph. 16% grade 6 minutes

| | |
|---|---|
| Min. Vent. at 37° | 77 L/min. |
| $O_2$ Cons./$M_2$ | 1385 cc. |
| $O_2V$ | 29.5 L. |
| R. Q. | 1.07 |
| M.V./MBC | 0.56 |
| Resp. Rate (6th min.) | 30/min. |
| Pulse Rate (6th min.) | 172/min. |

The Maximum Breathing Capacity is normal.

There was a slight increase of the % residual air due to a diminution of the vital capacity and to an increase of the residual air in liters; however, 37% is a border-line figure.

The Arterial Blood shows a significant diminution of the saturation and a diminution of the arterial $pO_2$ with an increase of the A.A. difference to 30 mm.Hg.

It is interesting to note that this relative unsaturation did not influence the capacity of this man for work when he is compared to the group of so called normal subjects his age. He consumes even a little more $O_2/M_2$ than the mean predicted value and at 3.5 mph. and 16% grade he does not hyperventilate much, his $O_2v$ being only 29.5 L.

One can also raise the question as to whether or not all persons subjected to prolonged heavy exposure will of necessity develop abnormal x-ray and physiological changes. This is not necessarily so as demonstrated by the next case.

Mr. L. L., 48 years old, spent 28 years in a very dusty place, the shipping department as shipper and shipping foreman in mills. This gave him a total of 504 units for duration and intensity of exposure. His x-rays (Fig. 4) show no evidence of asbestosis and he was classified 0. He had no complaints.

| | Det. | Pred. |
|---|---|---|
| M. B. C. | 158 L/min. | 139 L/min. |

| LUNG VOLUME | Det. | Pred. |
|---|---|---|
| T. Vol. | 6.57 L. | 6.57 L. |
| V. C. | 4.74 | 4.94 |
| F.R.C. | 2.59 | 2.47 |
| Resp. Res. | 0.76 | 0.86 |
| Resid. C. | 1.83 | 1.76 |
| % Resid./T. Vol. | 28% | 24.8% |

| ARTERIAL BLOOD AT EXERCISE: 3.5 mph. 10% grade 6 minutes | |
|---|---|
| $O_2$ Cons./$M_2$/cc. | 1105 cc. |
| $O_2$ Content | 19.79 Vol. % |
| $O_2$ Capacity | 21.73 Vol. % |
| % Saturation | 91.1 % |
| Alv. $pO_2$ | 93 mm.Hg |
| Art. $pO_2$ | 74 mm.Hg |
| A.A. Diff. | 19 mm.Hg |
| $O_2V$ | 24.1 L. |
| R. Q. | .83 |

| MAXIMUM EXERCISE: 3.5 mph. 12% grade 6 minutes | |
|---|---|
| Min. Vent. at 37° | 85.9 L/min. |
| $O_2$ Cons./$M_2$ | 1475 cc. |
| $O_2V$ | 28.0 L. |
| R. Q. | 1.12 |
| M.V./MBC | 0.55 |
| Resp. Rate (6th min.) | 30/min. |
| Pulse Rate (6th min.) | 160/min. |

The Maximum Breathing Capacity and the Lung Volume are absolutely normal. The blood data are also normal and the $O_2$ consumption in cc./$M_2$ at maximum exercise is higher than the mean normal.

Now going to group study. It should be re-emphasized that the men we have studied do not include all of the men exposed in any one plant nor, in addition, are these men random samples of the working population. The men were chosen on the basis that

they had the degree of exposure needed for the study, that they be free of extraneous disease (diabetes, etc.) and that they be willing to cooperate. Since, however, there was no deliberate bias, it will be profitable to consider certain groups with the reservation that our data may possibly not indicate the true proportion of abnormality that exists in the industry as a whole. Using the data that we have, we may proceed to certain questions.

First question: Does it exist a correlation between the duration and intensity of exposure and the development of x-ray patterns characteristic of asbestosis? Table I is self-explanatory.

Table I. EXPOSURE RATING VS X-RAY CLASSIFICATION

| Units Characterizing Exposure | 0 | $p^1$ | $p^2$ | $p^{2+}$ | | |
|---|---|---|---|---|---|---|
| 17 had not been exposed 0 | 11 | 5 | 1 | - | = | 17 |
| 3 had between 0 and 100 | 1 | 1 | 1 | - | = | 3 |
| 5 had between 100 and 200 | - | 2 | 3 | - | = | 5 |
| 23 had between 200 and 300 | 5 | 3 | 7 | 8 | = | 23 |
| 19 had between 300 and 400 | 4 | 2 | 4 | 9 | = | 19 |
| 7 had more than 400 | 1 | 1 | 2 | 3 | = | 7 |
| | 22 | 14 | 18 | 20 | | 74 |

There is no good correlation. Out of 23 cases who had 200 to 300 units, five or 20% are classified 0 and three $p^1$ still considered as normal. Eight or 35% were true asbestosis cases. About the same distribution is seen for exposure to higher concentrations. It is of interest that there were no severe x-ray changes in persons whose exposure rating was less than 200.

For the purposes of correlating exposure with various physiologic measurements, we have used only the men over age 40,

thus excluding the small group of seven men below that age. Table II shows that when the group is divided on the basis of severity of exposure, the age distribution is homogenous and hence can be neglected in the remainder of the tables related to exposure.

Table.II. EXPOSURE. Age over 40

| | Mean | S.D. | S.E. | △ | Significance |
|---|---|---|---|---|---|
| Normal | 50.9 | 5.23 | 1.09 | | |
| 0 | 50.7 | 6.78 | 1.75 | .2 | None |
| 200-300 | 49.2 | 6.91 | 1.51 | 1.7 | None |
| 300-400 | 48 | 6.58 | 1.64 | 2.9 | None |
| 400+ | 51.4 | 4.47 | 1.69 | .5 | None |

Table III. EXPOSURE VS M.B.C. Dst./L/Min.

| | Mean | S.D. | S.E. | ▷ | S.E. ▷ | Signi-ficance |
|---|---|---|---|---|---|---|
| Normal | 124.9 | 15.84 | 3.3 | | | |
| 0 | 128 | 15.44 | 3.99 | 3.1 | 5.18 | No S. |
| 200-300 | 111.5 | 23.34 | 5.09 | 13.4 | 6.07 | S. |
| 300-400 | 101.7 | 20.99 | 5.20 | 23.2 | 6.16 | S. |
| 400+ | 107.3 | 29.58 | 11.18 | 17.6 | 11.67 | No S. |

If we study the data, we can see that the mean is lower and significantly so specially for the subjects in the group 300 to 400, but some individual, are still in normal limits and the group of 400 and over has a higher figure than the preceding group, possibly due to the fact that the number of subjects is only 7 in this group.


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Table IV. EXPOSURE VS M.B.C. AS % OF PREDICTED

| | Mean | S.D. | S.E. | △ | S.E.△ | Significance |
|---|---|---|---|---|---|---|
| Normal | 100 | 17% | | | | |
| 0 | 94.5 | 13.9 | 3.60 | 1.6 | 4.6 | No S. |
| 200-300 | 81.4 | 15.64 | 3.41 | 11.5 | 4.57 | S. |
| 300-400 | 72.2 | 13.13 | 3.28 | 20.7 | 4.47 | S. |
| 400+ | 80.1 | 21.62 | 8.17 | 12.8 | 8.72 | No S. |

In % prediction , the same is true.

Tables III and IV disclose that there is a perceptible diminution of the Maximum Breathing Capacity in the exposed group but the reduction does not appear to bear any relationship to intensity and duration of exposure.

Table V. EXPOSURE VS TOTAL VOLUME OF LUNG

| | Mean | S.D. | S.E. | △ | S.E.△ | Significance |
|---|---|---|---|---|---|---|
| Normal | 5.93 | .97 | .20 | | | |
| 0 | 6.06 | .97 | .25 | .13 | .32 | No S. |
| 200-300 | 4.67 | .995 | .25 | 1.26 | .30 | S. |
| 300-400 | 4.76 | 1.028 | .26 | 1.17 | .33 | S. |
| 400+ | 5.03 | .98 | .37 | .90 | .42 | S. |


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Table VI. EXPOSURE VS VITAL CAPACITY

| | Mean | S.D. | S.E. | D | S.E.D | Significance |
|---|---|---|---|---|---|---|
| Normal | 4.12 | .63 | .13 | | | |
| 0 | 4.22 | .65 | .167 | .10 | .21 | No S. |
| 200-300 | 3.08 | .778 | .17 | 1.04 | .214 | S. |
| 300-400 | 2.96 | .647 | .16 | 1.16 | .21 | S. |
| 400+ | 3.22 | .83 | .313 | .90 | .34 | S. |

Tables V and VI disclose a definite restriction of the size to which the lung can be enlarged on full inspiration and of stroke volume in those persons exposed to asbestos fibre, but again there is no relationship between the magnitude of the change and the severity of exposure.

Table VII. EXPOSURE VS RESIDUAL AIR ABSOLUTE/L.

| | Mean | S.D. | S.E. | D | S.E.D | Significance |
|---|---|---|---|---|---|---|
| Normal | 1.81 | .466 | .097 | | | |
| 0 | 1.84 | .475 | .123 | .03 | .16 | None |
| 200-300 | 1.59 | .356 | .078 | .22 | .124 | None |
| 300-400 | 1.80 | .55 | .14 | .01 | .17 | None |
| 400+ | 1.80 | .48 | .18 | .01 | .20 | None |

Table VII shows that there is no interference with the degree to which the lungs can be emptied.


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Table VIII. EXPOSURE VS ARTERIAL BLOOD GASES DURING EXERCISE

| | 0 | 0-100 | 100-200 | 200-300 | 300-400 | 400+ |
|---|---|---|---|---|---|---|
| No. of Persons Studied | 17 | 3 | 5 | 23 | 19 | 7 |
| Mean % Hb. Sat. with $O_2$ | 94.9 | 93.4 | 88.2 | 90.2 | 91.3 | 92.4 |
| No. of Abnormal Persons | 0 | 0 | 3 | 10 | 7 | 1 |
| A.A. $O_2$ Difference | 20.9 | 23.0 | 31.5 | 31.4 | 27.3 | 30.1 |
| No. of Abnormal Persons | 0 | 0 | 3 | 12 | 6 | 2 |

Table VIII discloses that of the 57 exposed persons, approximately two-fifths evidenced definite impediment to the passage of $O_2$ from the alveoli into the pulmonary capillary blood. No ready explanation is available for the fact that there seems to be a more severe disturbance in this regard among those persons with less severe exposure as compared to those more severely exposed.

Table IX. MAXIMUM ATTAINABLE $O_2$ UPTAKE DURING EXERCISE

| | 0 | 200-300 | 300-400 | 400+ |
|---|---|---|---|---|
| Maximum $O_2$ Uptake as % of Predicted for Normal | 102% | 86% | 85% | 80% |
| No. of Persons Falling Below 2 S.D. from Prediction | 0 | 4 | 5 | 3 |

Each man was walked on the treadmill for six minutes at successively greater intensities of work until the maximum ability to increase $O_2$ uptake was reached. In a normal group previously studied in this laboratory, this ability was shown to correlate highly with age, thus permitting one to predict what value a


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normal person should attain with a coefficient of variation equal to 13.8%. Table IX discloses the relationship between asbestos exposure and capacity for maximum $O_2$ uptake (energy expenditure) in the men studied. Twelve of the persons were found to be distinctly subnormal and there does appear to be a slight but not good correlation with intensity of exposure.

To summarize, there is a striking lack of demonstrable correlation between the development of physiologic abnormalities and the severity of exposure to asbestos fibre as rated on the basis of duration and intensity of exposure.

A similar comparison of physiologic data and x-ray classification in an attempt to discover correlations was made. For this purpose we omitted the small group of seven men under 40 years of age. Table X shows a homogeneous distribution among the various categories of roentgenogram appearance as regards age; hence, the effect of age alone can be disregarded.

Table X. X-RAY CLASSIFICATION. Age over 40

| | No. of Cases | Mean | S.D. | S.E. | △ | Significance |
|---|---|---|---|---|---|---|
| Normal | | 50.9 | 5.23 | 1.09 | | |
| 0 | 22 | 48.2 | 7.25 | 1.66 | 2.7 | None |
| $p^1$ | 14 | 50.2 | 5.74 | 1.59 | .7 | None |
| $p^2$ | 16 | 48.7 | 6.69 | 1.73 | 2.2 | None |
| $p^{2+}$ | 22 | 52.0 | 5.95 | 1.33 | 1.1 | None |


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Tables XI and XII show that the Maximum Breathing Capacity is significantly low both in absolute quantity and as % of predicted normal values in categories $P^2$ and $P^{2+}$ but there is no apparent difference between the degree of change in Maximum Breathing Capacity of these two categories.

Table XI. X-RAY CLASSIFICATION VS M.B.C. Det./L/Min.

| | Mean | S.D. | S.E. | △ | Significance |
|---|---|---|---|---|---|
| Normal | 124.9 | 15.84 | 3.30 | | |
| 0 | 124.3 | 20.79 | 4.77 | .6 | No S. |
| $p^1$ | 112.2 | 27.52 | 7.63 | 12.7 | No S. |
| $p^2$ | 107.4 | 26.48 | 6.84 | 17.5 | S. |
| $p^{2+}$ | 106.5 | 19.46 | 4.35 | 18.4 | S. |

Table XII. X-RAY CLASSIFICATION VS M.B.C. AS % PREDICTED

| | Mean | S.D. | S.E. | △ | Significance |
|---|---|---|---|---|---|
| Normal | 100 | 17% | | | |
| 0 | 89.9 | 18.61 | 4.27 | 10.2 | No S. |
| $p^1$ | 82.6 | 17.88 | 4.96 | 17.4 | No S. |
| $p^2$ | 77.4 | 18.74 | 4.84 | 22.6 | S. |
| $p^{2+}$ | 79.8 | 12.20 | 2.73 | 20.2 | S. |

Inspection of Table XIII shows a striking diminution of Total Volume especially in those showing more severe roentgenographic change. That this reduction is due primarily to a diminution in the Vital Capacity is clearly shown in Table XIV.


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Table XIII. X-RAY CLASSIFICATION VS TOTAL VOLUME DET.

| | Mean | S.D. | S.E. | △ | Significance |
|---|---|---|---|---|---|
| Normal | 5.93 L. | .97 | .20 | | |
| 0 | 5.66 | .927 | .213 | .27 | No S. |
| $p^1$ | 5.81 | .882 | .245 | .12 | No S. |
| $p^2$ | 4.91 | .826 | .213 | 1.02 | S. |
| $p^{2+}$ | 4.10 | .759 | .170 | 1.83 | S. |

Table XIV. X-RAY CLASSIFICATION VS VITAL CAPACITY DET.

| | Mean | S.D. | S.E. | △ | Significance |
|---|---|---|---|---|---|
| Normal | 4.12 L. | .63 | .13 | | |
| 0 | 3.89 | .675 | .155 | .23 | No S. |
| $p^1$ | 3.88 | .744 | .206 | .24 | No S. |
| $p^2$ | 3.14 | .627 | .162 | .98 | S. |
| $p^{2+}$ | 2.62 | .489 | .109 | 1.50 | S. |

The residual air in absolute values shows no significant change except for a slight reduction as displayed in Table XV. As is shown in Table XVI there is a significant increase in the residual air expressed as a % of Total Volume but this is the result of a drop in Vital Capacity alone and in no way caused by an increase of the residual air.


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Table XV. X-RAY CLASSIFICATION VS RESIDUAL AIR ABSOLUTE

| | Mean | S.D. | S.E. | △ | Significance |
|---|---|---|---|---|---|
| Normal | 1.81 | .466 | .097 | | |
| 0 | 1.77 | .428 | .098 | .04 | No S. |
| $p^1$ | 1.93 | .43 | .119 | .12 | No S. |
| $p^2$ | 1.77 | .489 | .126 | .04 | No S. |
| $p^{2+}$ | 1.50 | .428 | .096 | .31 | S. |

Table XVI. X-RAY CLASSIFICATION VS RESIDUAL AIR AS % OF T.V.

| | Mean | S.D. | S.E. | △ | Significance |
|---|---|---|---|---|---|
| Normal | 30.4 | 4.40 | 0.92 | | |
| 0 | 31.3 | 5.34 | 1.23 | .9 | No S. |
| $p^1$ | 33.6 | 6.397 | 1.774 | 3.2 | No S. |
| $p^2$ | 35.9 | 7.85 | 2.03 | 5.5 | S. |
| $p^{2+}$ | 36.1 | 5.135 | 1.15 | 5.7 | S. |

These data on pulmonary volumina are of interest for two reasons. The histologists report the occurrence of "emphysema" as a prominent coincident lesion with asbestosis. In clinically significant diffuse obstructive emphysema, the residual air is always enlarged in absolute values. In our series, there is no evidence of an increase in residual air. This fact, considered together with the fact that the Maximum Breathing Capacity is only moderately reduced even in severe $P^{2+}$ cases is strong evidence that diffuse obstructive emphysema of a clinically significant degree is not a prominent or important feature of the functional aberrations attending asbestosis. Actually, the characteristic effect of

asbestosis on the pulmonary dynamics and volumina is to cause a restriction of lung mobility--well characterized as a "tight" or "restricted" lung. Inspection of the pulmonary volumina data strongly suggests that the abnormalities parallel the severity of x-ray abnormality.

The data shown in Table XVII shows that interference with the passage of $O_2$ across the alveolar membrane was not at all uncommon and occurred with increasingly great frequency as the changes in the roentgenogram were more pronounced. It is important to point out that the majority but not all of those categorized $P^{2+}$ (frank asbestosis) exhibited some abnormal degree of impediment to $O_2$ transfer. Of perhaps even greater interest is that some of those persons whose roentgenograms were not sufficiently abnormal to warrant a classification of $P^{2+}$ (frank asbestosis) also showed clearly recognizable abnormal impediment to $O_2$ transfer. This finding suggests that the roentgenogram is not necessarily the earliest and most sensitive indicator of injury caused by inhalation of asbestos fibre.

Table XVII. ARTERIAL BLOOD GAS STUDIES VS X-RAY CHANGE

Arterial Saturation During Exercise

| X-ray Category | Normal | 0 | $p^1$ | $p^2$ | $p^{2+}$ |
|---|---|---|---|---|---|
| No. of Cases | 36 | 22 | 14 | 16 | 22 |
| Mean % Saturation | 94.83 | 94.1 | 93.56 | 93.1 | 87.5 |
| S. D. | 2.33 | 2.32 | 3.63 | 4.5 | 6.64 |
| No. Abnormal Cases | None | None | 2 | 4 | 15 |


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Table XVII. (Continued)

Alveolar-Arterial $O_2$ Difference During Exercise

| | | | | | |
|---|---|---|---|---|---|
| Mean in mm.Hg | 19.6 | 20.1 | 22.0 | 27.0 | 36.0 |
| S. D. | 4.74 | 5.8 | 6.89 | 7.26 | 10.93 |
| No. Abnormal Cases | None | None | 3 | 5 | 15 |

In Table XVIII is shown the relationship between the maximum capacity for $O_2$ uptake during physical work of six minutes' duration and the pattern of the roentgenogram. There is a significant decrease in the $P^2$ and $P^{2+}$ groups but it is important to note that the majority of these two groups still retained normal capabilities for maximum $O_2$ uptake. This observation fits well with clinical experience. Although the data will not be shown until a subsequent publication, our evidence clearly shows a lack of any correlation between the occurrence or severity of arterial blood gas abnormality during exercise and the ability of the person to reach a high level of $O_2$ uptake during physical exercise.

Table XVIII. $O_2$ CONSUMPTION AT PEAK EXERCISE VS X-RAY CHANGE

$O_2$ Cons./$M_2$/cc./min. at Peak of Exercise in % of Predicted

| X-ray Category | Normal | 0 | $p^1$ | $p^2$ | $p^{2+}$ |
|---|---|---|---|---|---|
| No. of Cases | 36 | 22 | 14 | 16 | 22 |
| Mean | 100 | 99.98 | 96.42 | 86.11 | 76.25 |
| S. D. | 13.8 | 10.97 | 11.46 | 13.18 | 13.20 |
| No. Abnormal Cases | None | None | None | 2 | 9 |

Of the total group of 74 subjects in this study, 17 had never been exposed to asbestos fibre and in the sub-group no physiological abnormality was found. In the remaining 57 subjects, all of whom were occupationally exposed to asbestos fibre, physiological abnormalities were observed with the following frequencies.

| | |
|---|---|
| Subnormal Arterial $pO_2$ during exercise | 26 subjects |
| Abnormally increased Alveolar-arterial $O_2$ difference during exercise | 23 subjects |
| Subnormal Vital Capacity | 22 subjects |
| Arterial hemoglobin unsaturation during exercise | 21 subjects |
| Subnormal maximum ability for $O_2$ uptake during exercise | 12 subjects |
| Subnormal Maximum Breathing Capacity as % of predicted normal value | 9 subjects |

## Summary

This study dealt with 74 men of whom 57 cases had been subjected for many years to different concentrations of asbestos dust.

It was found that there was some but not good correlation between the duration and the intensity of exposure and the development of the x-ray pattern characteristic of asbestosis. Insofar as abnormal physiological data are concerned, a better correlation is found with the x-ray pattern than with intensity and duration of exposure.

The most frequent abnormalities were found to be a diminution of the arterial $pO_2$ and an increase of the A.-A. difference during exercise; a diminution of the vital capacity; and a diminution of the percentage of saturation of the arterial blood during exercise.

There is no true correlation, however, between these findings and the diminution of the capacity of a subject to work on a treadmill. A man can still be well saturated and unable to perform normally, while another one can be unsaturated and able to consume as much $O_2/M_2$ as the mean of normals his age.

This study shows that the physiologic abnormality is chiefly that of a "tight" lung that is expanded with difficulty and impairment of gas transfer between the gas and blood phases of the lung.

This is in rather striking contrast to the abnormality that is most commonly seen in silicosis, namely obstructive emphysema with its impairment of ventilation.

# APPENDIX

## Meaning of Abbreviations Used

| | |
|---|---|
| M.B.C. | Maximum Breathing Capacity |
| Det. | Determined |
| Pred. | Predicted |
| T. Vol. | Total Volume |
| V. C. | Vital Capacity |
| F.R.C. | Functional Residual Air |
| Resp. Res. | Respiratory Reserve |
| Resid. C. | Residual Capacity |

BLOOD AT EXERCISE

| | |
|---|---|
| 3 mph. | 3 miles per hour |
| 4% | 4 inches of slope per 100 inches length |
| $O_2$ Cons./$M_2$/cc. | Oxygen consumed per square meter of body surface are in cc. per minute |
| Alv. $pO_2$ mm.Hg | Pressure of oxygen in the alveoli in millimeters of mercury |
| Art. $pO_2$ | Pressure of oxygen in the arterial blood |
| A.A. Diff. | Difference of pressure in mm.Hg between the alveolar and the arterial oxygen |
| $O_2^v$ | Oxygen equivalent = the number of liters of air ventilated to consume one liter of oxygen. |


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## APPENDIX (Continued)

| | |
|---|---|
| S. D. | Standard Deviation |
| Min. Vent. at 37° | Ventilation in liters per minute at 37° centigrade |
| R. Q. | Respiratory Quotient |


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