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CAVITATION IN THE MASSIVE FIBROSIS OF COAL-WORKERS' PNEUMOCONIOSIS

BY

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The symptom of profuse black expectoration caused by cavitation of massive fibrosis in the lungs of coalworkers has been recognized for over a hundred years. It was originally recorded in Scotland by Gregory (1831), and Marshall (1834) described the sputum of his two cases as "presenting a closer resemblance to printer's ink than to any thing with which I can compare it." Thomson of Edinburgh published in 1837 a clinical and pathological account of "Black Expectoration and the Deposition of Black Matter in the Lungs" in coalminers from the Scottish lowlands, and, as a result of a questionary sent to several general practitioners in the Lothians and Fife, he found that miners often had black sputum. The black sputum of coalworkers was apparently well recognized in France in the last century and is frequently mentioned in Emile Zola's *Germinal*.

We recognize two forms of pneumoconiosis in coalworkers. The first, simple pneumoconiosis, is attributed simply to coal dust retention in the lungs and it does not progress after exposure to dust has ceased (Davies, Fletcher, Mann, and Stewart, 1949). Radiologically, simple pneumoconiosis is characterized by fine opacities, described and classified in the International System (Cochrane, Davies, and Fletcher, 1951) as indicated in Fig. 1. These opacities represent dust foci with or without focal emphysema (Gough, 1947; Heppleston, 1947, 1953). Men with simple pneumoconiosis may develop the second form of the disease which is characterized by the development of large localized opacities (Fig. 1) corresponding to the massive lesions found pathologically. It is rare for this condition to develop in a lung with less than category 2 simple pneumoconiosis; it nearly always progresses whether or not exposure to dust continues and it may start after the cessation of exposure to dust (Davies and others, 1949). It is called progressive massive fibrosis, the P.M.F. of Fletcher (1948). In South Wales men with simple pneumoconiosis develop P.M.F. at the rate of about 2% per annum (Cochrane, Fletcher, Gilson, and Hugh-Jones, 1951).

Cavitation in massive lesions may be recognized radiologically as a translucency, often with a fluid level, in the large opacities and clinically by the expectoration of large amounts of jet-black sputum. This profuse black expectoration (sometimes erroneously called melanoptysis) is quite different from the black-flecked sputum often seen in coalworkers after completing a shift. The frequency and nature of cavitation in massive fibrosis are not widely appreciated, despite the fact that extensive cavitation may be associated with few symptoms and may carry a prognosis which is much better than the radiological appearances at first suggest. It is our present purpose to emphasize these features by analysing a series of coalworkers with cavitated P.M.F. admitted to the Pneumoconiosis Research Unit ward at Llandough Hospital during 1946–52. An essential preliminary, however, is a brief consideration of the factors responsible for the development of P.M.F. and its cavitation.

THE NATURE OF MASSIVE FIBROSIS

Massive lesions in coalworkers are composed of dust and coarse, hyaline, collagen fibres irregularly mingled and containing foci of lymphocytes. Blood vessels and air passages are inconspicuous. Nevertheless, the previous existence of arteries and arterioles in massive lesions is revealed by persisting internal elastic lamellae after complete obliteration of the vascular lumina by invasion of fibrous tissue accompanied by dust phagocytes. Some vessels are only partially occluded, but, irrespective of the degree of stenosis, the elastic lamella is often reduplicated and disrupted (Fig. 2). Caseous foci may be found in massive lesions, but do not always show conclusive histological evidence of tuberculosis.

Radiological Classification of Coal Worker's Pneumoconiosis

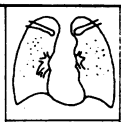
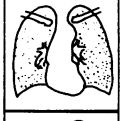
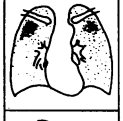
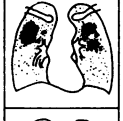
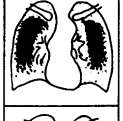
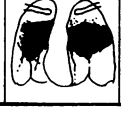
Pneumoconiosis	Category	Appearance
Simple (Pneumoconiosis with discrete opacities)	1	
	2	
	3	
Progressive Massive Fibrosis (Pneumoconiosis with coalescent or massive shadows)	A	
	B	
	C	
	D	

FIG. 1.

The features of massive fibrosis are quite dissimilar to those of the focal lesions, for which coal dust alone is held to be responsible (Heppleston, 1951). In the genesis of massive fibrosis, therefore, a factor (or factors) additional to the dust must operate, and for more than a hundred years (Gibson, 1834) tuberculosis has repeatedly been advanced as the complicating factor. The most thorough pathological investigation designed to test this concept is that of James (1954). In 40% of the massive lesions present in 245 South Wales coalworkers he found histological or bacteriological evidence of tuberculosis. Most massive lesions, however, show no definite evidence of tuberculosis, but such cases may well represent healed lesions, since the general pathological features of all massive lesions are similar irrespective of the presence or absence of tubercle bacilli. This view is supported by James's observations that tuberculosis was evident in 88% of massive lesions occurring in coalworkers under 40 years of age but in only 29% of massive lesions occurring in coalworkers of 60 years or over. The presence of tuberculous lesions and tubercle bacilli within the substance of massive fibrosis strongly suggests either that the organism reached this situation by being inhaled before or with the dust, or, if the bacilli were already present in the lung, that their activation occurred early in the period of dust exposure. As Merkel pointed out in 1888, it is difficult to believe that the bacilli penetrate into existing massive lesions. The experimental evidence is against a non-tuberculous infection in silicotic massive fibrosis (Gardner, 1937, 1938; Vorwald, Delahant, and Dworski, 1940). The radiological appearances of the early stages of P.M.F. closely resemble tuberculosis, and the raised erythrocyte sedimentation rate (E.S.R.) so often found during active progression of massive fibrosis (Stewart, Davies, Dowsett, Morrell, and Pierce, 1948) is in keeping with an infective process. The pathological features of massive fibrosis in coalworkers suggest that the infective process has been retarded in its rate of progress. Mann's (1951) and Cochrane's (1954) findings accord with this view. A tuberculous infection could readily account for the obliterative arterial changes seen in massive fibrosis, since comparable vascular effects are caused by fibrocaseous tuberculosis unassociated with industrial dust exposure (Fig. 3).

It appears that massive fibrosis in coalworkers may progress either because active infection continues or because partial vascular stenosis, left by an infection which has been overcome, leads to a replacement fibrosis. Vascular occlusion is also regarded as a factor in the progression of silicotic massive fibrosis (Policard, Croizier, and Martin, 1939). Complete obliteration of larger arteries is probably responsible for the patches of colliquative necrosis frequently seen in massive lesions. Extension of the necrotic process to involve a patent bronchus allows the liquefied material, looking like inspissated Indian ink and often loaded with cholesterol crystals, to be expectorated. A cavitated massive lesion results, its wall having a shaggy appearance but no lining to demarcate the cavity. At the margin of these ischaemic cavities the collagen fibres and remnants of dust cells simply disintegrate abruptly (Fig. 4), while cholesterol clefts may be numerous in the surrounding tissue, from which tubercle bacilli are very rarely recovered. Cavitation of massive fibrosis likewise follows when softening occurs in enclosed areas of caseous tuberculosis and a

bronchus is invaded. These tuberculous cavities may usually be distinguished macroscopically by the presence of a greyish wall and purulent-looking contents. Microscopically, tuberculous cavities have a necrotic lining with an eosinophilic, granular appearance. Surrounding the necrotic zone there is often a cellular layer of inflammatory type in which epithelioid cells and sometimes Langhan's giant cells may be recognized in diffuse or follicular arrangement (Fig. 5). From such lesions tubercle bacilli can usually be isolated. Occasionally both inflammatory and necrotic processes appear to be operating at different parts of the wall of the same cavity. The types of cavitation occurring in the massive fibrosis of coalworkers and in silicotic massive fibrosis (Vorwald, 1941) are thus closely comparable.

Methods

Routine medical and industrial histories were taken, and a clinical examination was carried out in each case. Postero-anterior radiographs were obtained in all cases and lateral films or tomograms in the majority. The sputa were examined for tubercle bacilli by stained smear, culture, and in many instances by guinea-pig inoculation. The E.S.R. was measured by the Westergren method.

Results

Of the 669 coalworkers admitted to the ward of the Pneumoconiosis Research Unit between 1946 and 1952, 389 had P.M.F. Cavitation in the massive lesions was discovered radiologically in 104 of these cases, a prevalence of 26.7%. The 104 cases fell into two main groups: (*a*) 26 patients with tubercle bacilli in the sputum during life, (*b*) 78 patients whose sputum did not contain tubercle bacilli in life, although bacilli were cultured from the lungs of one of them at necropsy. In group (*a*) acid-fast bacilli were found in one or more of the first five smears examined from 20 cases, and in the remainder bacilli were discovered either by further smears or by culture and animal inoculation. In group (*b*) only 18 cases had fewer than five specimens of sputum examined and the majority had many more, since a protracted search was made in patients whose initial specimens failed to reveal the organism. In the sputum-positive group, the finding of bacilli and the discovery of cavitation occurred simultaneously in 22 instances.

We have observed that in some cases of P.M.F. acid-fast bacilli seen in films of the sputum differ from tubercle bacilli in their cultural characteristics and fail to produce tuberculosis on inoculation into guinea-pigs. Two such cases are included in our sputum-negative group. Marks (1953) has noted that atypical acid-fast organisms occur more frequently in sputum specimens from cases of P.M.F. than from cases of pulmonary tuberculosis, and he stresses the need for animal inoculation to prove the pathogenicity of organisms isolated on culture from massive fibrosis. Neither of these two patients had had any anti-tuberculous chemotherapy before the finding of these organisms. Both have since died and the post-mortem findings were those of P.M.F. without evidence of active tuberculosis. Similar organisms have been found in five other cases of cavitated P.M.F. (not included in the present series), and none of these had had chemotherapy. It is possible that the organisms seen in two of the cases included in our sputum-positive group were also of this type, as the cases were originally assigned to this group on the result of stained smear examination. Guinea-pig inoculation was not carried out at that time, and subsequent specimens of sputum have failed to reveal acid-fast bacilli by any method.

Clinical Features.—Clinically, patients with cavitated P.M.F. may be considered in two main groups, those with and those without demonstrable tubercle bacilli in the sputum.

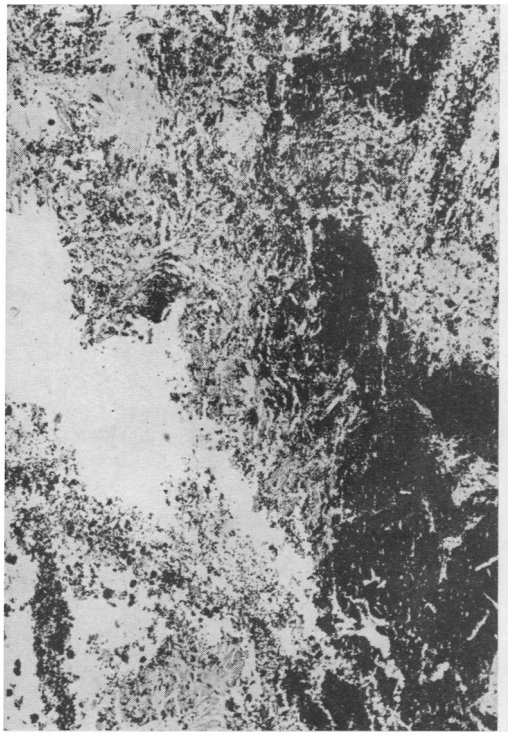
In the sputum-positive group of 26 cases, the radiological appearances were typical of P.M.F. and the sputum was positive for tubercle bacilli. Six patients were discovered to have cavitation and a positive sputum during the course of an acute respiratory infection, while in the other 20 tubercle bacilli were discovered in the course of routine investigation. Patients with unmodified tuberculosis superimposed on pneumoconiosis are not included in this investigation.

The sputum-negative group consisted of 78 cases. Cavitated P.M.F. was discovered in 43 of them during or immediately after a respiratory infection which usually resembled acute bronchitis, but in five instances there were features suggestive of pneumonia. In the remaining 35 patients cavitation was not associated with any other illness. One of these (Case 5) presented clinically as a pulmonary abscess two months after cavitation was first observed.

Table I gives the age distribution of the patients in the two main groups at the time of discovery of cavitation. Patients may occasionally be asymptomatic, but like many cases of P.M.F. they often complain of dyspnoea and cough. Black sputum and haemoptysis are relatively common, and Table II shows the frequency of their occurrence. The figures suggest no difference between the two main groups. In cases presenting with no history

FIG. 2.—Artery in a massive lesion from a coalworker, showing stenosis by fibrous thickening of the intima. Dust cells are inside the reduplicated internal elastic lamina. Elastin × 100.

FIG. 3.—Artery in fibrocaseous tuberculosis of the lungs in a man who had not worked in coal. Lumen obliterated by granulation tissue. Internal elastic lamina reduplicated. Elastin × 40.



4.—Margin of an ischaemic cavity in a massive lesion from a coalworker. Disintegration of fibrous tissue and dust cell remnants with cholesterol clefts in the surrounding tissue. Haematoxylin and eosin × 50.

5.—Tuberculous cavity in a massive lesion from a coalworker. Caseous foci are also present, together with an artery showing obliterative endarteritis. Haematoxylin and eosin × 25.

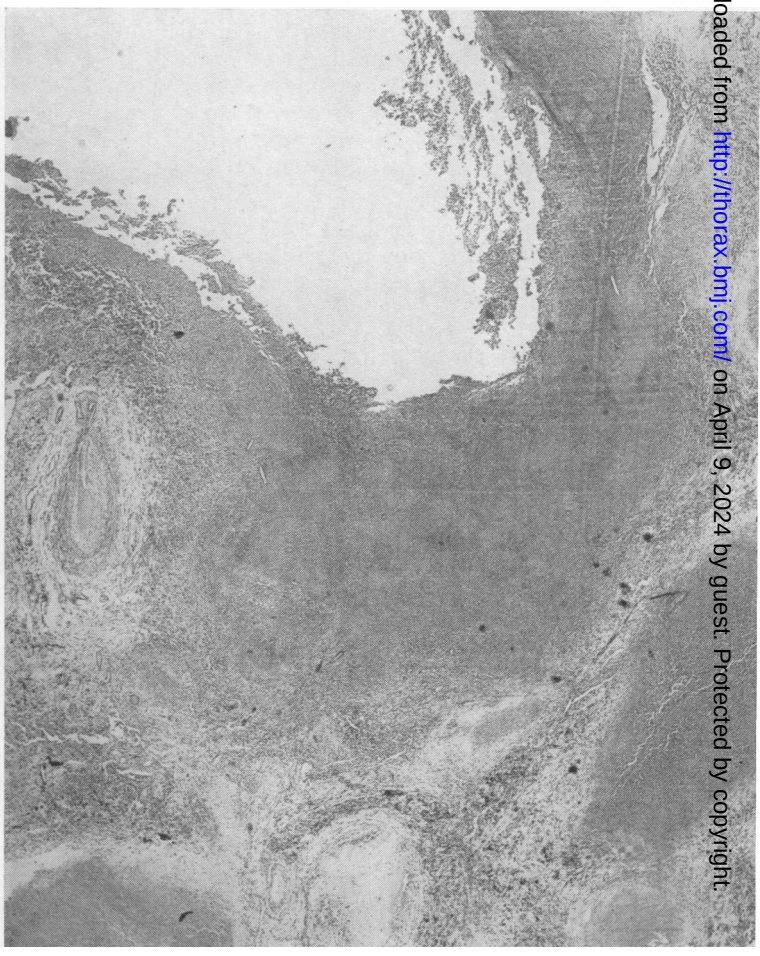


TABLE I

AGE DISTRIBUTION OF HOSPITAL IN-PATIENTS AT TIME OF DISCOVERY OF CAVITATION IN P.M.F.

Age Group	Number of Patients		Total
	Sputum-positive Group	Sputum-negative Group	
30–	1	5	6
35–	4	6	10
40–	5	22	27
45–	5	11	16
50–	6	19	25
55–	3	8	11
60–	2	5	7
65–	0	2	2
Total ..	26	78	104

TABLE II

OCCURRENCE OF HAEMOPTYSIS AND BLACK SPUTUM IN HOSPITAL IN-PATIENTS

	Sputum-positive Group	Sputum-negative Group	Total
Haemoptysis alone	2 (8%)	8 (10%)	10 (10%)
Black sputum alone	13 (50%)	27 (35%)	40 (38%)
Both	11 (42%)	36 (46%)	47 (45%)
Neither	0	7 (9%)	7 (7%)
Total ..	26 (100%)	78 (100%)	104 (100%)

of black sputum but showing cavitated P.M.F. radiologically it is reasonable to assume that the sputum has been swallowed. Severe haemoptysis is rare and occurred in only two of our patients, one sputum-positive and one negative.

PHYSICAL SIGNS.—Many different physical signs may be elicited in the chest, but their recognition is of little importance. Lee (1948) suggested that crepitations were more common in sputum-positive than in negative cases, but our figures show no difference. Crepitations were noted in 64 instances, 17 (65%) being sputum-positive cases and 47 (60%) sputum-negative cases. Marked finger clubbing only occurred in one patient (Case 5), although lesser degrees of clubbing were occasionally noted.

FEVER.—Seventeen (65%) of the sputum-positive and 44 (56%) of the sputum-negative cases had fever at some time during their stay in hospital (99° F. or over on two or more occasions), and therefore the presence or absence of fever is of little value in differentiating the two groups, although it has been suggested (Lee, 1948) that patients with overt tuberculosis are more commonly febrile.

GENERAL CONDITION.—The patients were graded as being in good, fair, or poor general condition, and although this is a very arbitrary assessment an analysis of the two groups is given in Table III.

TABLE III

GENERAL CONDITION OF HOSPITAL IN-PATIENTS

Condition	Sputum-positive Group	Sputum-negative Group	Total
Good	8 (31%)	33 (42%)	41 (39%)
Fair	4 (15%)	31 (40%)	35 (34%)
Poor	14 (54%)	14 (18%)	28 (27%)
Total ..	26 (100%)	78 (100%)	104 (100%)

It will be seen that a higher percentage of the sputum-positive patients were in poor general condition, but that a good general condition did not exclude open tuberculosis.

WEIGHT CHANGE.—An assessment of recent loss of weight was attempted, the patient's own estimate being taken to cover the period before admission to hospital. The only accurate measurements were in patients who had been in hospital for some time or who had previously attended the out-patient department. Table IV shows that only two patients in the whole series gained weight and

TABLE IV

WEIGHT CHANGE IN HOSPITAL IN-PATIENTS

Weight	Sputum-positive Group	Sputum-negative Group	All Cases
Gain	0	2 (3%)	2 (2%)
Static	7 (27%)	33 (42%)	40 (38%)
Slight loss	4 (15%)	24 (31%)	28 (27%)
Loss..	14 (54%)	18 (23%)	32 (31%)
No record	1 (4%)	1 (1%)	2 (2%)
Total ..	26 (100%)	78 (100%)	104 (100%)

that loss of weight is very common in both groups, although more so in those patients with a positive sputum.

ERYTHROCYTE SEDIMENTATION RATE.—The E.S.R. was measured in 98 of the 104 cases. It has been suggested by Nadiras, Batique, and Michot (1948) and Sander (1949) that a raised sedimentation rate in patients with pneumoconiosis and cavitation is indicative of overt tuberculosis. Taking 10 mm. in the first hour as normal, Table V shows that one sputum-positive case in our series had an E.S.R. below this, while 19 had an elevated figure, the range being 4 to 100 mm. in the first hour. Of the sputum-negative cases, four had an E.S.R. less than the norm, and 74 exceeded it. Thus mere elevation of the sedimentation rate does not indicate overt tuberculosis, nor does a low figure exclude it. Furthermore, it should be remembered that acute transient respiratory infections, which may raise the sedimentation rate, are frequent in patients with P.M.F.

TABLE V
MEASUREMENT OF THE E.S.R. OF HOSPITAL IN-PATIENTS

E.S.R.	Sputum-positive Group	Sputum-negative Group	Total
E.S.R. < 10 ..	1	4	5
E.S.R. > 10 ..	19	74	93
No record	6	—	6
Total ..	26	78	104

RADIOLOGICAL EXAMINATION.—If a coalworker suddenly expectorates a large quantity of jet-black sputum it may be assumed that cavitation has occurred in a massive lesion. Unless a radiograph is taken shortly after this episode, cavitation may not be detected because of the remarkable way in which cavities may refill completely (Case 4). The two main types of cavity in P.M.F. cannot be differentiated radiologically. Cavitation can usually be diagnosed from a postero-anterior radiograph, especially if a fluid level is present, but a lateral projection is sometimes useful to distinguish cavitation from translucent areas caused by emphysematous bullae. Tomography may be helpful (Belayew, 1951 ; Roche and Morel, 1952 ; Roche, Naudin, and Tolot, 1949), and examples of its use are shown in Cases 2 and 6. In our series cavitation was confirmed by lateral films or tomograms in 100 instances, while in the remaining four fluid levels made the cavitation obvious. Cavities may be single or multiple, unilateral or bilateral, and may occur in any part of the lung ; they differ in size and have walls of variable thickness (Figs. 8 and 10). Bronchography was carried out in a small number of the patients in our series (e.g., Case 5, Fig. 14). We have not yet observed contrast medium entering a cavity, although Worth (1952) and Balgairies and Bonte (1953) have done so. It is probable that the bronchial communication opens intermittently, so that the quantity of sputum and the fluid level change from time to time.

A preponderance of upper lobe cavitation was found in both groups (84% in the sputum-positive and 90% in the sputum-negative group), since P.M.F. occurs most commonly in these lobes. No cavities were discovered in the middle lobe, but a small number were found in the lower lobes particularly in the apical segments. Ornstein and Ulmar (1936) found cavitation in the upper lobes of 54 of their 58 cases, and when Vorwald (1941) compared 94 men with silicosis who had cavitation with 339 patients with uncomplicated tuberculosis he found that in both groups cavitation was commonest in the upper lobes. He agreed with Auerbach and Stemmerman (1944) that cavitation of the lower lobes occurs more commonly in tuberculosilicosis than in ordinary pulmonary tuberculosis.

DIFFERENTIAL DIAGNOSIS

Cavitation of massive fibrosis which is known to have been present from previous chest radiographs presents no problem of diagnosis other than the differentiation between sputum-positive and sputum-negative types of cavitation. Cavities occurring in the lungs of miners without evidence of simple pneumoconiosis should not be regarded as due to P.M.F., because this condition rarely arises on a background of less than category 2 simple pneumoconiosis. If emphysema has obliterated the background of simple pneumoconiosis there are usually other areas of massive fibrosis to indicate the diagnosis. In cases without previous chest radiographs and with a negative sputum, it is necessary to consider other causes of cavitation, such as have been reviewed by Balchum and Zimmerman (1952). A cavitated bronchial carcinoma (Reisner, 1936 ; Strang and Simpson, 1953) is probably the most difficult to exclude. Bronchoscopy was not performed routinely, and we doubt whether it is justifiable in typical cases of P.M.F. No carcinoma has been revealed in 31 of our cases coming to necropsy or in a further 49 of our cases who have been followed in life for more than two years. According to Shanks and Kerley (1951) sequestrum formation in a pulmonary cavity (other than in pneumoconiosis) is characteristic of aspergillosis, but in two of our cases (e.g., Case 6) there were sequestra in cavities with no evidence of fungal infection. It is surprising that secondary fungal infection did not occur in our cases especially as many of them had prolonged treatment by one or other of the modern antibiotics (Abbott, Fernando, Gurling, and Meade, 1952) for the acute respiratory infections to which they are prone.

PROGNOSIS

It has been suggested (Farrell, Sokoloff, and Charr, 1940) that the prognosis for patients with cavitated P.M.F. and a sputum negative for tubercle bacilli is relatively good, while for those with a positive sputum it is bad. Dayman (1945), Lee (1948), and Theodos and Gordon (1951 and 1952) give a life expectation in sputum-positive cases of between two and three years. In our series only three of the 26 patients survived two or more years after the discovery of a positive sputum. Only six of the sputum-positive group survived two or more years after the detection of the cavity, whereas 41 of the 78 sputum-negative cases survived longer than this after cavitation was

detected. The difference in survival in the two groups is presented in graphic form in Fig. 6. Although our records only date from 1946, radiographs taken previously are available in many instances, thereby providing a longer period of review. Patients with long-standing P.M.F. and a persistently negative sputum usually die of respiratory or cardiac failure, not of terminal tuberculous disease. It is possible that the more extensive use of modern anti-tuberculous drugs will improve the prognosis for patients with cavitated P.M.F. and a positive sputum. An attempt was made to compare the times of survival after the diagnosis of sputum-negative cases of P.M.F. with and without cavitation. The 78 patients with cavitation in the sputum-negative group were paired with 78 other ward patients of comparable age and radiological category who had non-cavitated P.M.F. and a negative sputum. It will be seen from the graph that, of sputum-negative patients with P.M.F., those with cavitation have a slightly better expectation of life than those without cavitation. The difference is not great and may probably be accounted for by the way in which cases are selected for hospital admission. Many of the patients with cavitated disease were admitted for investigation although they were in their usual health, while patients with non-cavitated P.M.F. were usually admitted because they were unwell.

Management and Treatment

Definitive treatment of patients with cavitated P.M.F. is not possible, but some of them remain surprisingly well despite gross structural lung damage.

Sputum-positive Cases.—Our experience in the treatment of cases of cavitated P.M.F. with a positive sputum is small, for we were not able to keep them in our ward. Few results of the treatment of this condition have been published, but in cases of silicosis with a positive sputum anti-tuberculous drugs have been found to confer some symptomatic benefit although they have not markedly improved the survival period (Boselli and Lusardi, 1950; Lang, 1951; van Mechelen, 1951; Stojadinovic and Stojadinovic, 1952; Cohen and Glinsky, 1953). Cox (1953) has had experience of many cases of cavitated P.M.F. with a positive sputum in South Wales and is in general agreement with these authors.

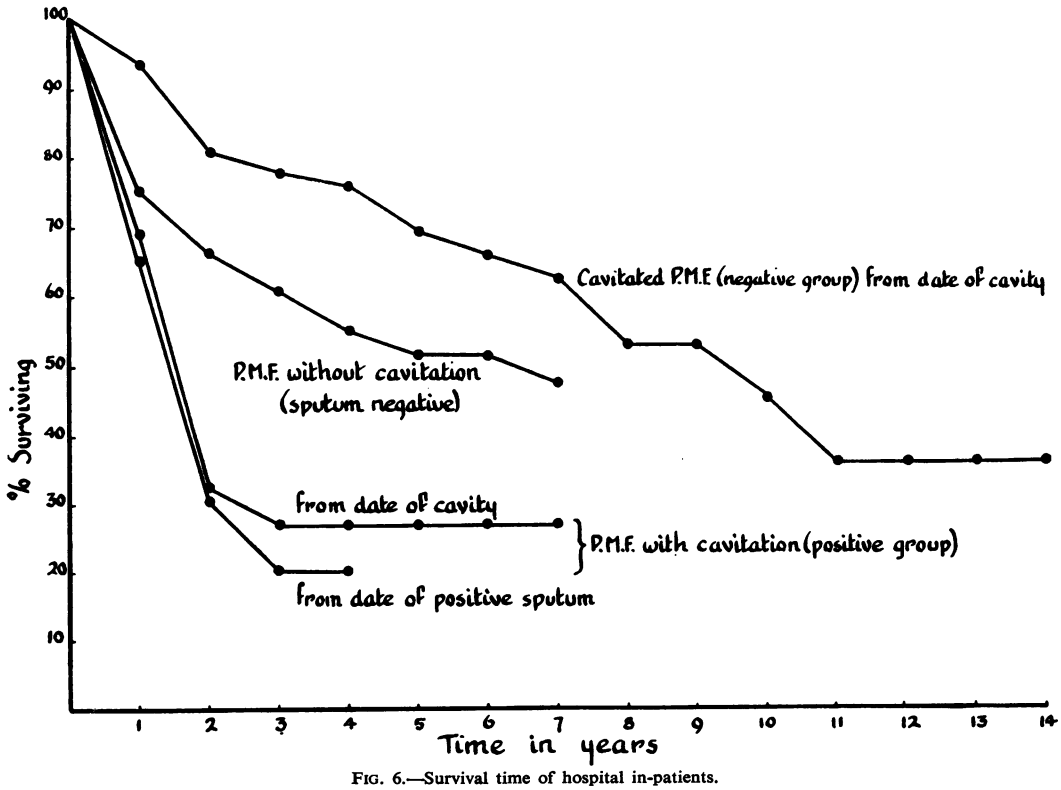


Fig. 6.—Survival time of hospital in-patients.

Pulmonary collapse has been employed as a method of treatment by some workers. Artificial pneumothorax and thoracoplasty were found to be unsuccessful by Auerbach and Stemmerman (1944), and Theodos and Gordon (1951 and 1952) agree in general but report one successful thoracoplasty. Maier and Hurst (1946) described one patient with unilateral cavitated silico-tuberculosis with a positive sputum who became sputum-negative after an extrapleural pneumothorax.

SPUTUM-NEGATIVE CASES.—The general management and treatment of patients with pneumoconiosis will be discussed fully elsewhere (Kilpatrick, 1955). There is no specific therapy, but patients with the sputum-negative type of cavitation may remain fairly well for many years and are frequently able to undertake gainful employment. It is very important to explain to these men that the black sputum and blood which they expectorate are not evidence of overt tuberculosis, for they are naturally apprehensive, and much harm may be done by doctors who do not appreciate the relatively benign nature of cavitated P.M.F. in the absence of a positive sputum (see Case 2). Non-specific acute respiratory infections can be considerably helped by appropriate antibacterial treatment. Eventually, increasing dyspnoea makes all patients progressively more disabled, and death from cor pulmonale is common.

DISCUSSION

A hospital in-patient population is highly selected and conclusions drawn from such a sample may well be biased. Admission to hospital is likely to be sought by men who have the striking symptom of black sputum, and we encouraged several such patients to come in for investigation. The proportion of sputum-positive cases will be increased by the tendency to admit patients who are relatively ill or who have recently lost weight, but it will be decreased by the exclusion from a general hospital ward of those known to have a positive sputum before admission. All these factors have influenced our sample. The effect of selection is illustrated by a comparison of the prevalence of cavitation in P.M.F. in our ward population with that found in the Rhondda Fach Survey, where 95% of the whole population of 6,026 miners and ex-miners were radiographed (Cochrane, Cox, and Jarman, 1952). During this survey 736 cases of P.M.F. were discovered, but only 18 had cavitation, giving a prevalence of 2.4% compared with 26.7% in our ward population. From only three (17%) of the 18 men in the Rhondda Fach Survey were tubercle bacilli found by laryngeal swab. Thus the prevalence of cavitation in our ward population was ten times as great as that found in a mining community. There is thus a great discrepancy between the prevalence of cavitation found in a single survey of a complete community and that observed in ward patients over a period of six years. Stewart and others (1948), in following up certified cases of pneumoconiosis for periods as long as 14 years, found on the basis of a history of black sputum that 15% of cases with P.M.F. probably had cavitation.

Other factors than selection for admission may also contribute to these discrepancies. Our in-patients had several radiographs taken over a period of years in contrast to the single film taken during the Rhondda Fach Survey. Cavitation may only appear in one or two of the serial radiographs, either because it occurs late in the period of observation or because a cavity may refill and thus disappear radiologically. Further, the prevalence of cavitation will depend upon the proportions of early and late stages of P.M.F., since cavitation usually occurs in radiological categories B to D, and these categories are more common in the ward population than in the communities from which they are drawn. While selection increases the prevalence of cavitation in a ward population, a single field survey underestimates it owing to refilling of cavities. To discover the proportion of cases of P.M.F. which may be liable to undergo cavitation within a given period (the "attack rate") it would be necessary to take radiographs of a sample of cases at short intervals over many years. It is unlikely that this would ever be done because, in the absence of positive sputum, cavitation is a relatively unimportant clinical event. The importance of defining the population studied is further emphasized by the frequency with which a positive sputum is found in cases of P.M.F. under different circumstances. In the Rhondda Fach Survey this was 1.1% (Cochrane and others, 1952) compared with 7.7% in our ward population (30 positive in 389 cases) and 40% at necropsy (James, 1954).

Our observations, both clinical and pathological, lead us to conclude that in the massive fibrosis of coalworkers' pneumoconiosis several factors play a part in producing cavitation. The centre of many massive lesions shows liquefaction, which is probably due to ischaemic necrosis, and cavitation is inevitable when this softened zone communicates with a bronchus. This may occur spontaneously when gradual extension of necrosis reaches a bronchus or it may be accelerated by an acute respiratory infection in the region of the bronchus

concerned. An interesting feature of the sputum-negative cases is the absence of secondary infection of the cavity itself, and this allows most patients to continue enjoying fairly good general health for years after cavitation has occurred. It is difficult to see why these cavities should differ in respect of their liability to secondary infection from cavities such as occur in neoplastic, bronchiectatic, and cystic lungs. The repeated and prolonged expectoration of large amounts of black sputum is a remarkable sight, and Marshall (1834) noted that one of his patients expectorated "as much as two English pints in 24 hours." The matter consists of accumulated bronchial secretion mixed with coal dust and cellular debris. It can readily be demonstrated that a very small quantity of carbon (e.g., 1 ml. of Indian ink) is sufficient to give half a pint of sputum a jet-black appearance.

Our contention is that P.M.F. is at the outset a modified form of tuberculosis, and we must therefore conclude that in a majority of cases the infection dies out leaving a scar which may increase in extent following partial vascular occlusion. In the remainder, viable tubercle bacilli must persist within the mass and for some reason resume multiplication after prolonged quiescence, eventually leading to cavitation and to a fatal outcome in most cases within two years despite antibacterial treatment. The pathological evidence makes it difficult for us to believe that the presence of tubercle bacilli in massive fibrosis merely represents a secondary bacillary invasion of a lesion primarily due to some other undetermined cause.

Summary

Massive fibrosis occurs in coalworkers whose lungs already contain a certain amount of coal dust and is probably tuberculous in origin. Cavitation often occurs in massive fibrosis, and it appears to be due to two basic processes, tuberculosis or ischaemic necrosis, acting alone or in combination.

Cavitation was discovered in 104 patients with P.M.F. admitted to the Pneumoconiosis Research Unit ward between 1946 and 1952. Of these 104 cases, 26 had tubercle bacilli in the sputum during life and 78 cases did not, although bacilli were cultured from the lungs of one of the latter group at necropsy. Difficulty in classification may arise from the findings of non-pathogenic acid-fast bacilli in the sputum and the importance of animal inoculation is evident.

Fever, loss of weight, toxaemia, and an elevated E.S.R. are not reliable guides to the differentiation between sputum-positive and sputum-negative cases because the frequent non-tuberculous respiratory infections in patients with P.M.F. may affect these clinical findings.

The prognosis for patients in the sputum-positive group is poor, few surviving for more than two years after the appearance of tubercle bacilli in the sputum. In the absence of a positive sputum the prognosis for patients with cavitated P.M.F. is no worse than for non-cavitated P.M.F.

Treatment is unsatisfactory, but the sputum-positive cases should be given anti-tuberculous drugs for the symptomatic benefit frequently conferred. In sputum-negative cases cavitation is of little clinical significance, and such cases only require reassurance and possibly symptomatic treatment.

APPENDIX

ILLUSTRATIVE CASES

Sputum-positive Group

Case 1.—E. C. H., aged 36, worked underground in house and steam coal pits for 20 years, mostly at the coal face, but left the pits when he was 34 years of age because of dyspnoea on exertion and fatigue. He was first seen in 1948, at the age of 36, when a chest radiograph revealed moderately advanced P.M.F. without cavitation, the sputum being negative for tubercle bacilli on direct examination and on culture at this time. In 1950 he felt less well, the cough and sputum increased, he was more dyspnoeic and further radiography revealed that cavitation had occurred in the mass in the right lung (Fig. 7). The sputum was positive for tubercle bacilli on direct examination, culture, and guinea-pig inoculation.

During treatment by bed rest and a course of streptomycin and *para*-amino salicylic acid (P.A.S.) the cough became less troublesome, the sputum negative and less in quantity, the temperature normal, and the E.S.R. lower. A month after cessation of antibiotic therapy, however, fever returned with a worsening of symptoms and the sputum again became positive. The general condition improved after a further course of streptomycin and P.A.S., but the sputum remained positive. Death occurred two years and two months after tubercle bacilli were first isolated.

Deterioration of patients with P.M.F. and a positive sputum is commonly even more rapid than in this case.

Sputum-negative Group

Case 2.—D. O., aged 38, from the age of 14 worked underground in steam coal pits for a total of 18 years. He worked at the coal face and on the conveyors. Progressive massive fibrosis with cavitation was discovered when he was admitted to our ward in 1948, at the age of 38 (Figs. 8 and 9). In 1950 a routine radiograph taken elsewhere led to his being referred to a chest clinic, when he was advised to give up his job and rest at home because he was presumed to be suffering from open pulmonary tuberculosis. At this time he

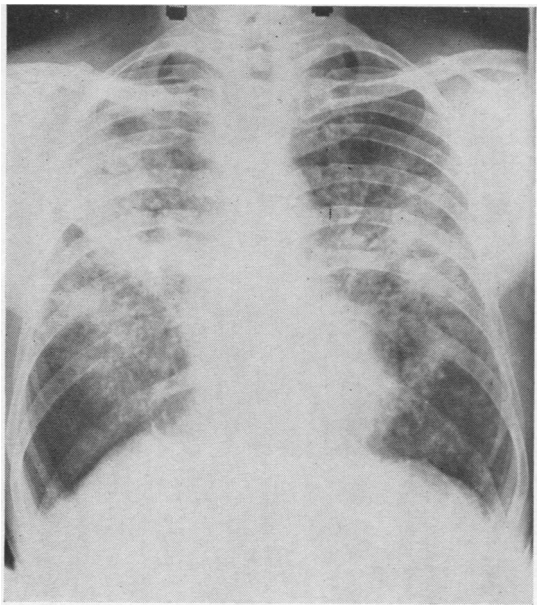


FIG. 7.—Case 1. Radiograph of chest, showing bilateral P.M.F. with cavitation in the upper zone of the right lung. The sputum was positive for tubercle bacilli.

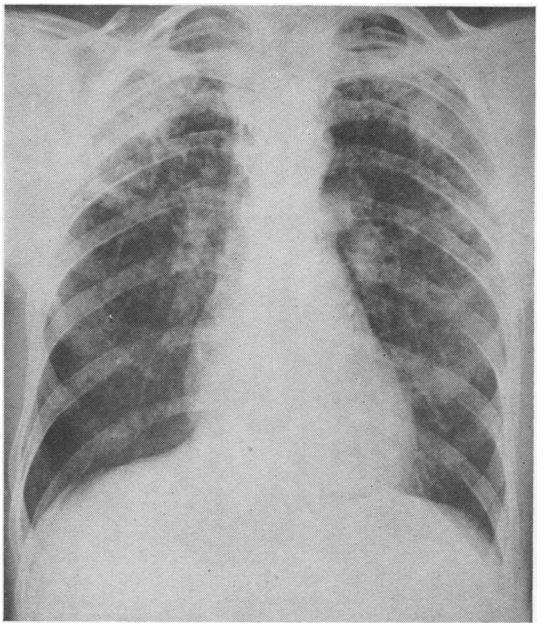


FIG. 8.—Case 2. Radiograph taken in 1948 showing bilateral P.M.F. In the mass in the upper part of the right lung there is an area in which cavitation is suggested but is not obvious.

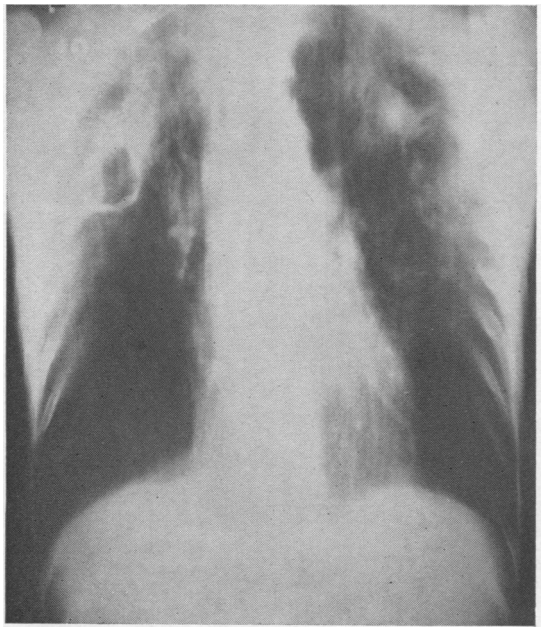


FIG. 9.—Case 2. Tomograph confirming the presence of cavitation; the cavity wall is thick and irregular. The existence of cavitation was an incidental finding at this time, and repeated examinations of the sputa have been negative for tubercle bacilli.

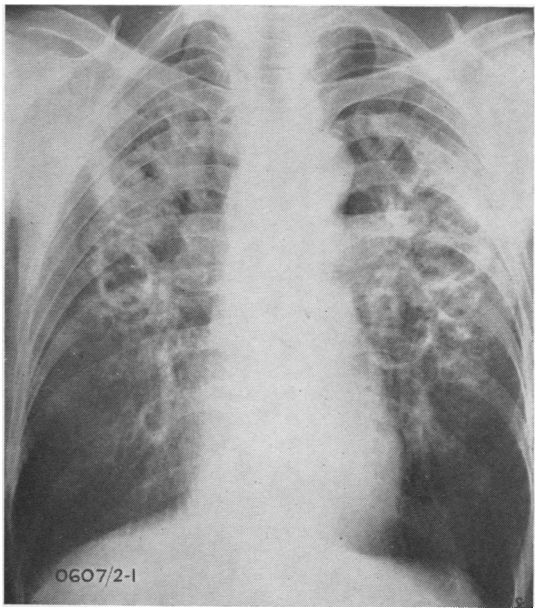


FIG. 10.—Case 3. Radiograph of chest showing extensive bilateral multiple cavitation of P.M.F. in a coalminer aged 54. The sputum has been repeatedly negative for tubercle bacilli.

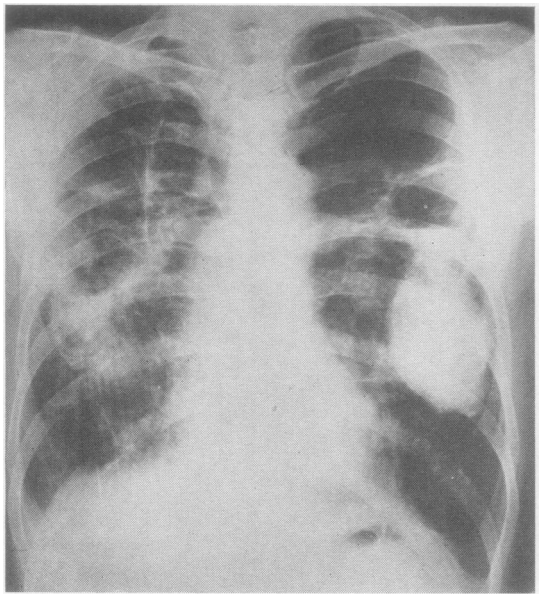


FIG. 11.—Case 4. Radiograph of chest showing P.M.F. with bilateral cavities and fluid levels. The region of extreme translucency in the left upper zone is an area of bullous emphysema. The sputum was negative for tubercle bacilli.

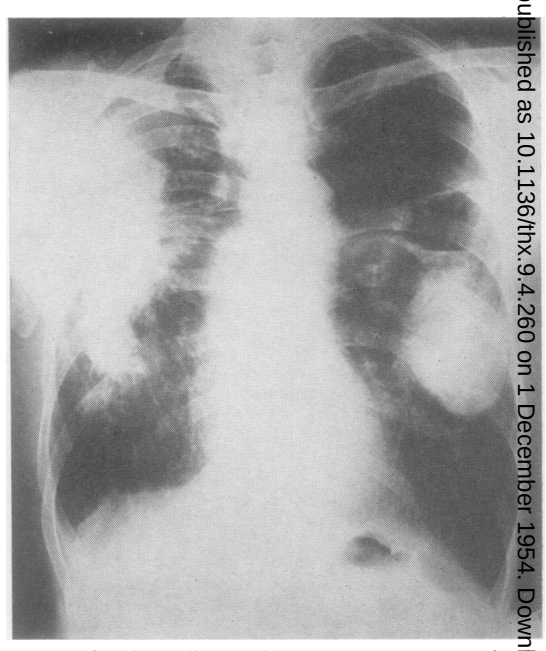


FIG. 12.—Case 4. Radiograph three years later than Fig. 11, showing that the cavity system in the right lung has completely refilled. The appearances of the left lung are unchanged.

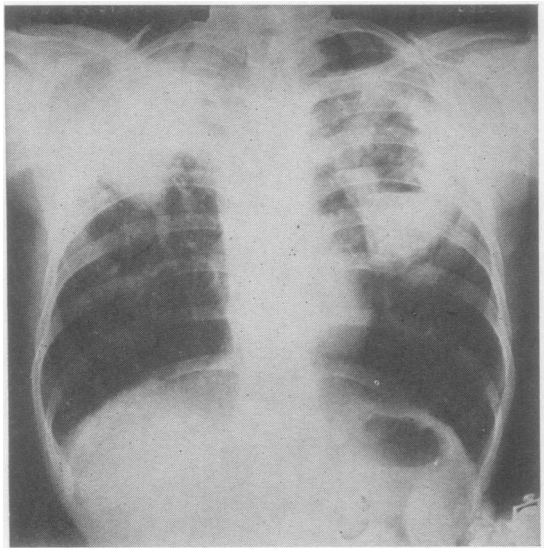


FIG. 13.—Case 5. Radiograph of chest in 1951, showing bilateral massive shadowing with a large cavity in the left lung with a fluid level.

FIG. 14.—Case 5. Tomograph more than a year later showing that the cavity was still present. The sputum was negative for tubercle bacilli.

was feeling well and repeated examination of the sputum failed to reveal tubercle bacilli. This is an example of a man who suffered loss of employment owing to a misunderstanding of the significance of cavitation in massive fibrosis. He remains well at the present time and the sputum is persistently negative for tubercle bacilli.

Case 3.—This man, W. R., was aged 54 when examined radiographically by us in 1947 (Fig. 16). He had worked for 30 years in a steam coal colliery, mostly at the coal face, but had spent two years drilling in rock. Extensive bilateral cavitation was first discovered in 1946, but there was no history of black sputum to indicate when it had occurred. He is still able to lead a quiet life and the cavities have remained more or less the same although

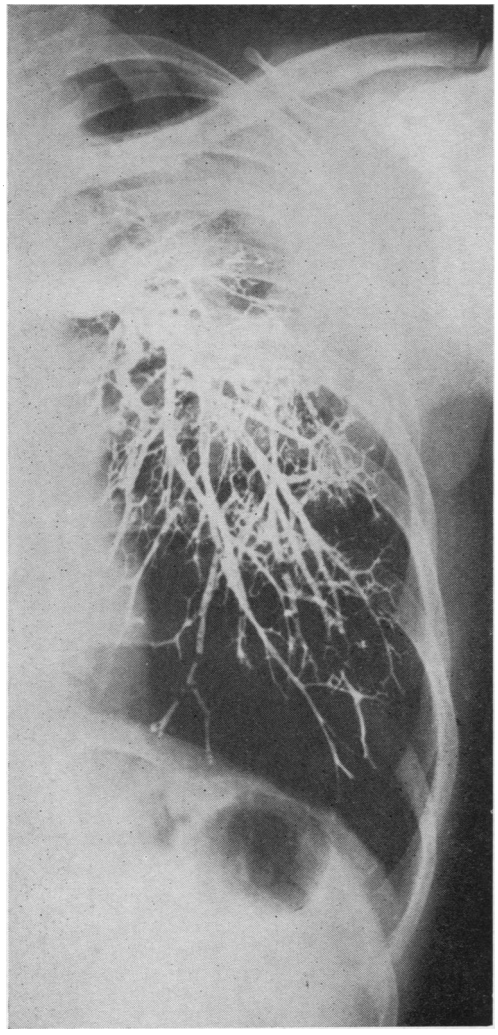


FIG. 15.—Case 5. Bronchography shows the radio-opaque medium approaching, but not entering, the cavity. Considerable distortion of the remainder of the bronchial tree is evident, but no bronchiectasis is visible.

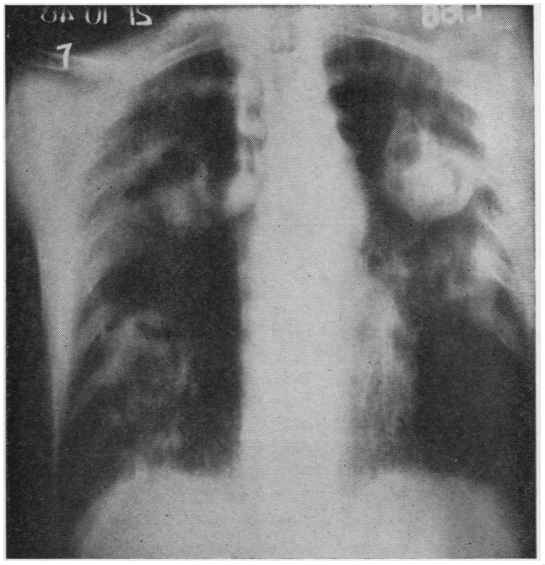


FIG. 16.—Case 6. Tomograph showing an unusual appearance of sequestrum formation inside a cavity. The sputum was negative for tubercle bacilli and the patient remains well.

they have emptied and refilled from time to time. Between 1946 and 1949 he had very little systemic upset, but since that time his general condition has slowly deteriorated and dyspnoea increased. The E.S.R. is usually above 50 mm. in the first hour, and the sputum has been repeatedly negative for tubercle bacilli on direct examination, culture, and animal inoculation. This case shows that a man can live for many years despite extensive cavitation.

Case 4.—This man, L. A., worked at the coal face of an anthracite colliery for 25 years. He was admitted to hospital in 1949 at the age of 46 for treatment of an attack of "bronchitis" associated with black sputum. A radiograph taken at that time (Fig. 11) showed a large cavity in the right lung. It was noted three years later (Fig. 12) that the cavity had refilled. In October, 1951, he was re-admitted to hospital with a further respiratory infection associated with copious black sputum, and radiography revealed that the cavity had emptied once more. A total of 28 specimens of sputum were negative on direct smear and 20 were negative on culture for tubercle bacilli. This case illustrates the way in which a cavity may empty and refill from time to time.

Case 5.—This man, J. T., spent 17 years in steam coal pits working at the coal face, but left in 1933 because of dyspepsia. When he was first admitted to hospital at the age of 50 in 1951 he gave a history of copious black sputum for four weeks and said he had been breathless on exertion for several years. Fig. 13 shows the radiographic appearance at the time of admission, and, as a result of being in hospital where postural drainage was carried out, the black sputum ceased. The E.S.R. varied between 70 and 120 mm. in the first hour, and the

sputum was negative for tubercle bacilli. He was re-admitted two months later, as the cough was more marked, the sputum purulent, even more copious, and on this occasion foul smelling. Again, no tubercle bacilli were isolated, the sputum containing only mixed organisms with no one type predominating; no fungi were found. The E.S.R. remained between 40 and 100 mm. in the first hour, and as a result of treatment by large doses of penicillin and streptomycin the sputum became less purulent. Radiography, however, showed no change in the appearance of the cavity, and in 1952 (Fig. 14) tomography showed that the cavity persisted although the patient was feeling well. Bronchography (Fig. 15) was carried out, but the opaque medium did not enter the cavity and no bronchiectasis was demonstrated in the remainder of the lung. This case has therefore behaved clinically as a chronic lung abscess and is the only one in our series in which secondary infection has apparently occurred in cavitated P.M.F. and is also the only patient who showed marked finger clubbing. Cases of a similar type have been described by Seltmann (1867), Cummins and Sladden (1930), Ornstein and Ulmar (1936), Badham and Taylor (1940), and Faulkner (1940), but no such case has been found in over 2,000 necropsies performed on coalworkers in the Pathology Department of the Welsh National School of Medicine.

Case 6.—This man, G. G., illustrates an uncommon finding. He was first examined in 1948 when he was 37 years of age, as he had noticed that his sputum was black and that he was dyspnoeic on exertion. He had worked for 16 years at the coal face in an anthracite colliery. Cavitation was plainly visible in the postero-anterior film and tomography revealed an unusual appearance in the left lung (Fig. 16), which was presumably a sequestrum of necrotic material lying within a cavity. The patient remains well, the sputum has been repeatedly negative for tubercle bacilli, and subsequent radiography has shown that the cavity has refilled.

We wish to acknowledge our indebtedness to our colleagues in the Pneumoconiosis Research Unit and the Department of Pathology of the Welsh National School of Medicine, and particularly to Dr. J. C. Gilson (director) for continual advice and encouragement; to Dr. A. L. Cochrane and Dr. I. Davies for their assistance in *x*-ray reading; and to Mr. P. D. Oldham for statistical advice.

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