Original article

Scand J Work Environ Health 1983;9(4):303-314

doi:10.5271/sjweh.2407

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This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/6314495

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Scand j work environ health 9 (1983) 303–314

Graphite pneumoconiosis

A review of etiologic and epidemiologic aspects

by Rolf Hanoa, MD, MSc[1]

HANOA R. Graphite pneumoconiosis: A review of etiologic and epidemiologic aspects. *Scand j work environ health* 9 (1983) 303–314. Six hundred and five cases of graphite pneumoconiosis have been reported in the literature. In 39 cases the diagnosis was based on or supported by autopsy or lung biopsy results. Only 14 of the 39 cases were presented with relatively complete documentation as to details about dust exposure. Only one of these completely documented cases suggested that nearly pure graphite may cause graphite pneumoconiosis. Eleven experimental studies on animals dealt with the effect of graphite dust on various tissues, and nine with the effect on lung tissue. The three studies on the effect of pure or nearly pure graphite gave no unanimous conclusion. Five out of six studies dealing with graphite containing silica demonstrated fibrogenic effect on the lungs. Most of the 18 epidemiologic studies of workers exposed to graphite dust are invalid because they do not comply with ordinary methodologic requirements. The present state of knowledge does not exclude the possibility that analytically pure graphite may cause pneumoconiosis although the majority of the evidence indicates that pneumoconiosis is a mixed-dust type of lung reaction.

Key terms: carbon dust pneumoconiosis, graphitosis, mixed-dust pneumoconiosis, silicosis.

Graphite is either natural or synthetic. *Natural graphite* (plumbago) is elemental crystalline carbon with many different mineral impurities (53, 56). Graphite is widely distributed geographically. There are mines in Canada, Mexico, Brazil, Norway, West Germany, Italy, Czechoslovakia, Austria, the Soviet Union, Korea, China, India, Sri Lanka, Madagascar, and Zimbabwe. Natural graphite contains variable quantities of silica. Of the total silica content, that of free silica is the most interesting because of its fibrogenic potential for the lungs. Quartz is the most common crystalline type of free silica. The content of free silica varies from 11 % in samples from Italy to 3.6 % in samples from Sri Lanka. Natural graphite usually contains other impurities such as iron oxide, clay, mica, and other minerals. Natural graphite is either of the crystalline flake type or of the cryptocrystalline, amorphous type.

Synthetic or artificial graphite is crystalline carbon made by subjecting coal or petroleum coke to a temperature of 2,200–3,000°C in an electric furnace. Synthetic graphite contains, in general, only very small quantities of free silica. But synthetic graphite may be used in workplaces where the employees are also exposed to other types of dust. Both the mining and curing of natural graphite and the production of synthetic graphite have been relatively dusty processes.

Graphite has many useful properties, and for the manufacture of many products it has few or sometimes no substitutes. Natural graphite is used to make blast furnace hearths, as well as linings and crucibles and ladles for the chemical and nonferrous metallurgical industries (53). Natural graphite is used in foundry facings. In steel and cast iron manufacturing natural graphite increases the hardness and strength of the metal. Amorphous natural graphite is used in pencils. Both

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natural and synthetic graphite may be used as a component or alone as a lubricant. Neutron moderators in atomic reactors can be produced from synthetic graphite. Synthetic graphite is also used in the manufacture of carbon electrodes. Natural graphite was also used in the past in electrotyping.

It is important not to confuse graphite with *other carbon substances* encountered in occupational medicine, eg, coal, lamp black, and carbon black (53). *Lamp black* is an amorphous carbon used mainly as a paint pigment and an oil-absorption agent. It contains no quartz. *Carbon black* is hard, brilliant and mainly crystalline. It is used in rubber, plastics, printing inks, paints, and enamels and in the manufacture of carbon electrodes and carbon paper. Pneumoconiosis due to carbon black has been reported by, among others, Miller & Ramsden (44).

In this review *graphite pneumoconiosis* is defined as pneumoconiosis in workers exposed to graphite dust at the workplace. The term graphite pneumoconiosis does not imply that carbon is the only or main etiological factor in the pneumoconiosis. The term *pure graphite pneumoconiosis* (or graphitosis), used by some authors, is applied when the authors claim the pneumoconiosis is caused solely or mainly by carbon. *Mixed-dust pneumoconiosis* applies to pneumoconiosis caused by congruent exposure to crystalline silica and other dusts such as carbon. *Silicosis* is defined as a pneumoconiosis which is primarily due to free silica. The term should not be used for "coal pneumoconiosis and other types of pneumoconiosis the features of which are entirely different even if free silica may play some part in their pathogenesis [p 134]" (53).

Koopmann (37) was the first to publish a case report of graphite pneumoconiosis. From the autopsy he described the condition as extensive pneumoconiosis with cavities resulting from necrosis, chronic interstitial pneumonia, peribronchiolitis, and periarteritis nodosa. The cavities were not caused by tuberculosis. There had been no clinical symptoms. The pneumoconiosis was not the cause of death. Koopmann presented his case as if the pneumoconiosis was caused by carbon alone.

Lochtkemper & Teleky (41) were the first authors to point out the role of quartz in the etiology of pneumoconiosis in workers exposed to graphite dust. They did not consider carbon to be the only etiological factor in their three reported cases. They criticized Hollmann (29) for disregarding the quartz impurities in coal and graphite. Hollmann published three cases of pneumoconiosis among workers exposed to coal dust or coal and graphite dust. He maintained that the men had been exposed to pure carbon dust, although no dust analyses had been done.

The first published cases of graphite pneumoconiosis which included clinical, radiographic, and autopsy details were reported by Faulkner (16), and by Dunner (9) and Harding & Oliver (26) in cooperation. The main features of the case of Dunner/Harding & Oliver were as follows: HD, aged 67, had worked in a graphite mill grinding Korean graphite (natural graphite containing free silica) for 19 years. He had never had another job with dust exposure. Eight years after leaving the graphite mill he lost weight and developed marked dyspnea. He had very little sputum and not much cough. There was dullness to percussion in the right subclavicular region. A radiograph of his chest showed a massive homogeneous opacity in the right upper zone, a small rounded opacity overlying the hilum of the right lung, a homogeneous opacity of less density in the left upper zone, a rounded opacity the size of a golf ball overlying the left hilum, and a fine mottling in the midzones of both lungs. Autopsy showed adhesions between the upper parts of each lung and the chest wall. Black pigment, similar to graphite, was seen in the pleural lining of the chest wall and throughout the lungs, which were jet black. On palpation there was a firm fibrous mass in each of the lobes of the lungs. In the center of each mass there was necrosis and a cavity filled with black semi-solid material. There were also three fibrotic nodules. No evidence of tuberculosis was present. Histological examination revealed widespread focal emphysema, which was somewhat masked by edema, some purulent bronchitis, and bronchopneumonia. There were very many small areas of linear and radial fibrosis, but nothing resembling the classical whorled silicotic lesion.

Since 1924 several reports of cases of

graphite pneumoconiosis have appeared, the last case reports coming from Norway (25) and Japan (30) (table 1). Various views on the etiology of graphite pneumoconiosis have been presented. The two most common points of view have been (i) that the pneumoconiosis is caused solely or mainly by carbon and (ii) that graphite pneumoconiosis is a mixed-dust pneumoconiosis. The views of the different authors are presented in table 1.

Many authors have been preoccupied with the resemblance between graphite pneumoconiosis and coal worker's pneumoconiosis. Both have a simple and a progressive massive stage. The location in the lung zones may be the same. Both natural graphite pneumoconiosis and coal worker's pneumoconiosis may show eggshell calcification and clubbing. Radiographs are similar for the two conditions, and there are no principal differences between the histological lesions of the two conditions, which are quite different from nodular silicosis. The occupational history is essential to differentiate between graphite pneumoconiosis and coal worker's pneumoconiosis.

The relatively large quantity of scientific articles about graphite pneumoconiosis may reflect the expectation that these studies would throw light upon the etiology and pathogenesis of coal worker's pneumoconiosis as well. The role of free silica in the etiology and pathogenesis of coal worker's pneumoconiosis is disputed (53). This dispute has a practical bearing upon the choice of standards for the prevention of coal worker's pneumoconiosis. Studies by Jacobsen (32) suggest that quartz exposure of less than 10 % of coal mine dust does not affect the probability of developing pneumoconiosis. The incidence of simple coal worker's pneumoconiosis is chiefly related to the mass of respirable dust over the period of exposure (72). However experimental studies on animals have not produced unanimous results as to the effect of coal and quartz in the lungs (53).

One would expect pure coal dust (without free silica) and pure graphite dust to act in the same way on lung tissue. If one could unambiguously show that pure graphite dust clinically or experimentally might cause pneumoconiosis, the result would have a bearing on the coal pneumoconiosis dispute too.

Experimental studies of the effect of graphite dust on various tissues

Eleven experimental studies have been done to determine whether graphite dust is fibrogenic and could cause pneumoconiosis (1, 2, 8, 15, 26, 49, 50, 52, 57, 58, 61, 64). Most of the experimental studies have used rats. In six of the studies the animals have been exposed to natural graphite containing some silica (2, 15, 26, 57, 58, 61). Synthetic graphite has been used in four studies (2, 52, 57, 64). Two investigations have used both natural and synthetic graphite (2, 57). In three studies the type of graphite (and in two of them the silica content) was not specified (1, 8, 49, 50).

In most of the experiments the animals were exposed to graphite applied intratracheally or by inhalation. The results of the 11 experiments are heterogeneous. There is no unanimous conclusion as to whether pure or nearly pure graphite is fibrogenic in the lungs. Bovet (2) demonstrated that pure graphite causes slight pulmonary fibrosis. Pendergrass et al (57) showed that nearly pure graphite was inert. Drowatzky (8) found no significant silicosis as a result of exposure to graphite with less than 1 % free silica. Graphite containing silica was considered to be fibrogenic in the lungs of animals by Harding & Oliver (26), Ray et al (61), Ottowicz & Paradowski (52), Pendergrass et al (57), and Drowatzky (8). Engelmann (15) found no such effect. After all, the 11 experiments do not leave much certainty as to the etiology and pathogenesis of graphite pneumoconiosis. The results suggest however that graphite containing silica is fibrogenic in lung tissue.

Clinical reports of graphite pneumoconiosis

Approximately 605 cases of graphite pneumoconiosis are reported in the literature. The term "approximately" is used because in a few instances two different reports refer to the same cases. When allowance is made for this fact, the true number of reported cases would be about 540. Some reports are presented in a way that makes it difficult to determine exactly how many cases are reported. The numbers of reported cases are presented in table 1 with

Table 1. Cases of graphite pneumoconiosis reported through 1982.

Author	Year of publication	Number of cases	Type of dust	Type of workplace	Diagnostic methods	Authors' view of the nature of the graphite pneumoconiosis
Koopmann (37)	1924	1	Graphite (probably natural), no dust analysis	Graphite mill	Autopsy, post mortem radiography	Pure graphite pneumoconiosis, silica not mentioned
Hollmann (29)	1928	3	1. Dept – coal 2. Dept – graphite and coal (natural?)	Manufacture of rods of carbon	Radiography, clinical examination	Pure graphite and coal pneumoconiosis, silica (rock) said not to be present
Lochtkemper & Teleky (41)	1932	A. 3	Graphite (natural) with 4–6 % silica	A. Crucible manufacture	A. Radiography, clinical examination	A. Mixed-dust graphite pneumoconiosis
		B. 1	Graphite (natural) with silica and stone containing quartz	B. Fireproof stone manufacture	B. Radiography, clinical examination	B. Silicosis
Kaestle (34)	1932	6	Graphite (natural) with silica	Graphite mine and curing factory	Radiography, clinical examination	Mixed-dust graphite pneumoconiosis
Faulkner (16)	1940	1	Graphite with a large quantity of silica and iron	Stove foundry	Radiography, clinical examination, autopsy	Anthracosis, silicosis, siderosis
Dunner & Bagnall (9, 10, 12 13)	1945–1949	5	"Pure" graphite (natural?), no dust analysis	?	Radiography, clinical examination, autopsy in one case	Pure graphite pneumoconiosis or silica pneumoconiosis
Dassanayake (7)	1948	A. 4	Ceylon graphite (natural), no dust analysis	A. Graphite mine	A. Radiography, clinical examination	A. Unspecified diffuse fibrosis
		B. ?	Ceylon graphite (natural), no dust analysis	B. Graphite curing sheds	B. Radiography, clinical examination	B. Unspecified diffuse fibrosis
Gloyne et al (21)	1949	A. 1	Graphite (natural?) with silica	A. Wharf for unloading raw material, chiefly graphite	A. Radiography, clinical examination, autopsy	A. Mixed-dust graphite pneumoconiosis
		B. 1	Graphite with silica, coal and gypsum	B. Mill grinding raw materials as graphite	B. Radiography, clinical examination, autopsy	B. Mixed-dust graphite pneumoconiosis
Harding & Oliver (26)	1949	A. 3	Graphite (natural) with 4–10 % free silica	A. Graphite grinding	A. Autopsy, radiography and clinical examination in two cases	A. Mixed-dust graphite pneumoconiosis
		B. 6	Graphite (natural) with 4–10 % free silica	B. Graphite grinding	B. Radiography	B. Mixed-dust graphite pneumoconiosis
Parmeggiani (54, 55)	1950	24	Graphite (natural) with 11 % free silica	Graphite mine, graphite mill, electrode manufacture	Mass miniature radiography, clinical examination	Mixed-dust graphite pneumoconiosis
Jaffe (33)	1951	1	Graphite (natural) with silica, no dust analysis	Graphite mine	Radiography clinical examination, histology	Pure graphite pneumoconiosis
MacMahon (42)	1952	1	Graphite (synthetic?), no silica demonstrable	Electrotype molding	Autopsy	Caused by graphite, pneumoconiosis
Rüttner et al (63)	1952	1	Graphite (synthetic?) and carborundum	Manufacture of graphite	Radiography, clinical examination, autopsy	Not silicogen graphite-carborundum pneumoconiosis
Müller (45, 46, 47)	1953	A. 15	Graphite (natural) with 3–4 % silica + other additives	A. Graphite curing	A. Radiography, clinical examination	A. Mixed-dust graphite pneumoconiosis, cause not clear
		B. 14	Graphite (natural) with 3–4 % silica + other additives	B. Crucible manufacture	B. Radiography, clinical examination	B. Mixed-dust graphite pneumoconiosis, cause not clear
Güttner (23)	1953	A. 1	Graphite (natural?), no dust analysis	A. Crucible manufacture	A. Radiography, clinical examination, autopsy	A. Mixed-dust pneumoconiosis?
		B. 1	Graphite (natural?), no dust analysis	B. Graphite mill	B. Radiography, clinical examination, autopsy	B. Mixed-dust pneumoconiosis?
Brauss (3)	1954	8	Graphite (synthetic?), no free silica	Graphite processing plant	Radiography, clinical examination	Pure graphite pneumoconiosis
Engelmann (15)	1954	A. 5	Graphite (natural) with 2.7 % free silica	A. Graphite mill	A. Radiography, clinical examination, autopsy	A. Mixed-dust pneumoconiosis
		B. 1	Graphite (natural) with 5–20 % free silica	B. Graphite mine	B. Radiography, clinical examination, autopsy	B. Mixed-dust pneumoconiosis
		C. 4	Graphite (natural) with 2.7–20 % free silica	C. Graphite mine and graphite mill	C. Radiography, clinical examination, autopsy	C. Mixed-dust pneumoconiosis
Haferland (24)	1957	1	Graphite (natural) with silica	Graphite mill and pottery	Radiography, clinical examination, autopsy	Mixed-dust pneumoconiosis (graphite silicosis)
Koelsch (35)	1958	A. 6	Graphite (natural) with silica	A. Graphite mine and curing factory	A. Radiography, clinical examination	A. Mixed-dust pneumoconiosis
		B. 19	Graphite (natural?), no dust analysis	B. Graphite processing	B. Radiography, clinical examination	B. Mixed-dust pneumoconiosis
Hirsch et al (28)	1959	1	Graphite (natural), no dust analysis	Graphite mine	Radiography, clinical examination, histology	Graphite pneumoconiosis, no specified view, tuberculosis complication
Zahorski (74)	1960	24	Graphite (synthetic), with "very little" silica	Carbon electrode plants	Radiography, clinical examination	Mixed-dust pneumoconiosis, silica played an activator role

(continued)

Table 1. (Continued)

Author	Year of publication	Number of cases	Type of dust	Type of workplace	Diagnostic methods	Authors' view of the nature of the graphite pneumoconiosis
Lister (39)	1961	1	Graphite (synthetic) with 0.02 % free silica	Lathe operator in small factory producing graphite bars	Radiography, clinical examination	"Nearly pure" graphite pneumoconiosis
Sklensky & Berka (67)	1963	4	Graphite (natural) with 5 % free silica	Graphite mine and drying station	Radiography, clinical examination	Not graphitosis but graphite silicosis, mixed-dust pneumoconiosis
Okutani et al (48)	1963	112	Graphite with 0.1 % free silica	Carbon electrode manufacture	Radiography, clinical examination, autopsy (2 cases)	Graphite pneumoconiosis
Coscia et al (6)	1963	38	Graphite (natural) with free silica	Graphite mine	Radiography, clinical examination	Pneumoconiosis, no expressed opinion
Casalone & Rasetti (5)	1963	9	Graphite (natural?) with 12 % free silica	Pipe manufacture	Radiography, clinical examination	Silicosis
Gaido et al (19)	1963	36	Graphite (natural) with 20–30 % silica	Graphite mine	Radiography, clinical examination	Silicosis
Koschnitsky et al (38)	1964	15	Graphite (natural) with silica	Graphite mine and curing factory	Radiography, clinical examination	Silicosis
Gaensler et al (18)	1966	4	Graphite (natural) with silica	Electrotype molding in printing industry	Clinical examination, radiography (3 cases), autopsy (3 cases)	Progressive massive fibrosis – not silicosis, but silica played "a small role, if any"
Radionov et al (59)	1967	7	Graphite (natural) with silica	Graphite mine and curing factory	No details given	Silicosis
Pendergrass et al (56, 57)	1967	11	Various types of natural graphite, many exposed to other types of dust too	A. 7: various parts of graphite industry B. 4: graphite plants in Pennsylvania	A + B. Radiography, clinical examination, biopsy (2 cases), autopsy (3 cases)	A. + B. Mixed-dust pneumoconiosis "largely the result of free crystalline silica"
Town (68)	1968	1	Graphite (natural) with silica	Graphite mine and mill	Radiography, clinical examination, autopsy	Graphite pneumoconiosis
Ranasinha & Uragoda (60)	1972	78	Graphite (natural) with free silica	Graphite mine	70-mm radiography, clinical examination of 73 cases	Mixed-dust pneumoconiosis, not a silicosis, not a pure carbon pneumoconiosis
Lister & Wimborne (40)	1972	1	Graphite (synthetic), with 0.02 % free silica	Lathe operator in a small factory producing graphite bars	Radiography, clinical examination, autopsy	Nearly pure graphite pneumoconiosis
Uragoda (69)	1972	3	Graphite (natural) with free silica	Graphite mine	Radiography, clinical examination	Tuberculosis-pneumoconiosis
Uragoda (70)	1972	1	Graphite (natural) with free silica	Graphite mine	70-mm radiography, clinical examination	Graphite pneumoconiosis complicated by tuberculosis
Einbrodt (14)	1973	1	Graphite with free silica	Graphite mill	Autopsy	Anthraco-silicosis with lymphnode tuberculosis
Koizumi et al (36)	1974	1	Graphite (not specified) with silica	Milling graphite, a factory producing graphite powder for blackboards	Radiography, clinical examination	Mixed-dust pneumoconiosis due to graphite and silica
Zahorski et al (75)	1975	86	Graphite (artificial) with silica	Coal electrode production, milling plant	Radiography, clinical examination	Mixed-dust pneumoconiosis, like coal worker's pneumoconiosis
Uragoda & Rajendra (71)	1975	32	Graphite (natural) with low silica content	Graphite curing	Radiography, clinical examination	Mixed-dust pneumoconiosis with graphite and silica as causes
Hanoa (25)	1981	1	Graphite (natural) with 10 % silica	Graphite mine and curing	100-x-100-mm mass radiography, clinical examination	Mixed-dust pneumoconiosis
Inoue et al (30)	1982	1	Graphite, not specified	Not specified	Radiography, clinical examination autopsy	Graphite lung with tuberculous granulomas

the surname of the author, the year of publication, the type of graphite, type of workplace, diagnostic methods, and each author's opinion of the etiology of pneumoconiosis.

Many authors have provided only scanty data with regard to the type of graphite concerned (natural or synthetic), the silica content of dust, and the exposure of their cases to other types of dust. According to the data given by the authors, the 605 cases can be distributed as shown in table 2.

For 167 reported cases there is no information as to whether the cases have been exposed to natural or synthetic graphite; 326 cases are reported as being exposed to natural graphite, and 112 are reported as exposed to synthetic graphite.

The 605 cases worked in a wide range of different workplaces. Table 3 shows the distribution of cases by different types

Table 2. Reported cases of graphite pneumoconiosis according to type of graphite.

Type of graphite	Number of cases
Graphite, no details	32
Graphite, no details, but with silica	126
Graphite, no details, but without silica	9
Graphite with silica	
Natural	310
Synthetic	112
Graphite without silica	
Natural	–
Synthetic	–
No information on silica content	
Natural	16
Synthetic	–
Total	605

Table 3. Reported cases of graphite pneumoconiosis according to type of workplace.

Type of workplace	Number of cases
Mine	163
Mine and mill (or curing)	44
Mill or curing only	66
Graphite manufacture unspecified	40
Manufacture of crucibles, electrodes, and carbon bars; electrotyping; foundries; etc	261
No information or unspecified or more than one type	31
Total	605

Table 4. Clinical methods applied to establish the diagnosis of graphite pneumoconiosis.

Clinical methods	Number of cases
Clinical examination, radiography	449
Clinical examination, radiography, biopsy	4
Clinical examination, radiography, autopsy	30
Radiography alone	6
Autopsy alone or autopsy plus clinical examination	5
Mass radiography, clinical examination	99
Other combinations or no information	12
Total	605

Table 5. Authors' view of the etiology of graphite pneumoconiosis.

Etiology	Number of authors
Pure graphite pneumoconiosis	6
Nearly pure graphite pneumoconiosis	2
Mixed-dust pneumoconiosis	20
Silicosis	5
Not specified or other views	8
Total	41

of workplace.

A large proportion of cases had been exposed to graphite dust during their work in graphite mines. Nearly half of the cases were engaged in industries using graphite in the production process or in the final product.

Most reported cases of graphite pneumoconiosis were diagnosed on the basis of a clinical examination and chest radiograph (table 4). In only 39 cases was the diagnosis based on or supported by autopsy, or lung biopsy during life. In 14 of these cases (15, 26, 40) details were presented as to the type of graphite dust and content of silica. The 10 cases of Engelmann (15) involved exposure to natural graphite with a free silica content of at least 2.7 %. The cases of Harding & Oliver (26) had exposure to natural graphite dust containing 4–10 % free silica. The case of Lister & Wimborne (40) had exposure to synthetic graphite containing less than 0.02 % free silica. These 14 cases are the only completely documented cases of graphite pneumoconiosis in the literature. In 25 of the 39 cases with autopsy or lung biopsy there was no information as to the type of graphite and/or the content of silica. For these 25 cases a detailed description of the dust and the exposure would have been particularly valuable.

Etiology of graphite pneumoconiosis

Nearly all the authors present their opinion about the etiology of graphite pneumoconiosis. In table 5 the opinions of various authors are distributed in different categories. A few authors are counted more than once because they have published more than one study with case reports. But different reports based on the same cases and written by the same author are only counted once.

One-half of the authors looked at graphite pneumoconiosis as a mixed-dust pneumoconiosis, ie, caused by both silica and graphite dust. Eight authors consider graphite alone, or above all other agents, as the cause of graphite pneumoconiosis (3, 18, 29, 33, 37, 39, 40, 48, 68).

Koopmann (37), Hollmann (29), Jaffe (33), and Town (68) did not present any

analysis of the graphite dust in the workplace. Jaffe (33) and Town (68) reported cases with exposure to natural graphite. Gaensler et al (18) presented cases with exposure to natural graphite. Their data suggest a very low content of free silica, but the analysis of dust in the workplace was not complete. Brauss (3) presented cases with exposure to graphite dust with no demonstrable free silica. In the study of Okutani et al (48) graphite (unspecified) dust in the workplace contained 0.1 % free silica. The case presented by Lister (39) and later by Lister & Wimborne (40) involved exposure to synthetic graphite dust with 0.02 % free silica. MacMahon (42) presented a case of exposure to graphite (unspecified) with no demonstrable silica; the author expressed no definite opinion as to the etiology of the pneumoconiosis. None of the authors giving details about the content of free silica specified whether the content referred to the respirable dust or to the total dust.

The only reports which suggest that pure graphite may cause graphite pneumoconiosis are those of Brauss (3) and MacMahon (42). The only reports which suggest that nearly pure graphite may cause graphite pneumoconiosis are those of Okutani et al (48), Lister (39), and Lister & Wimborne (40).

Epidemiologic studies of workers exposed to graphite

Table 6 gives a survey of epidemiologic studies. There are 20 reports of 18 such studies of workers exposed to graphite dust. Two of the reports present investigations which have already been presented in earlier reports. Nine of the studies describe employees in mines, or in a mine and curing factory combined.

Sixteen of the 18 studies were cross-sectional. One investigation by Zahorski et al (75) seems to be a cohort study, and another study by Zahorski (74) a period prevalence investigation (but this is not made clear by the author). There are no case-referent studies. Only the two investigations by Gaido et al (19) and Ranasinha & Uragoda (60) used reference groups. Only the studies by Hollmann (29), Bruusgaard (4), Parmeggiani (54, 55). Müller (45, 46, 47), Koelsch (35), Uragoda & Rajendra (71), and Hanoa (25) gave details about the population size and sampling methods.

Hanoa (25) did his study in the same Norwegian graphite mine as Bruusgaard (4) did 47 years earlier. In the 1930s this little mining community was very isolated, only accessible by sea, and Bruusgaard had no facilities for radiographic examination there.

Table 6 presents the investigation methods of the 18 epidemiologic studies. Radiographic examination would be sufficient to sort out the possible cases of pneumoconiosis. Clinical examination and history would be necessary to establish the diagnosis and the type of pneumoconiosis. Numerous different classifications of pneumoconiosis are applied in the different studies. The present classification of the International Labour Office (ILO) (31) was not applied in any of the 18 studies.

The prevalence rates of the investigations vary greatly. The highest prevalence rates were those of Coscia et al (6) – 73 % – and Gaido et al (19) – 72 %. With two exceptions the studies of employees in the graphite industry in Europe did not show a very wide prevalence range, eg, there were Kaestle (34) with 5 %, Parmeggiani (54, 55) with 6 %, Sklensky & Berka (67) with 7 %, Koschnitsky et al (38) with 8 %, Radionov et al (59) with 4 %, and Hanoa (25) with 1 %. The last study comprised all the employees in the mining company.

The variation in prevalence rates can partly be explained by the differences in (i) the definition of the population at risk, (ii) the sampling methods, (iii) the methods and standards of examination, (iv) the classification of pneumoconioses. Because of these many differences it would not be meaningful to relate reported prevalence rates to varying silica content in the graphite dust.

The differences in prevalence rates may of course also reflect real variation in the prevalence of graphite pneumoconiosis. In 12 out of the 18 studies the minimum number of years of exposure to develop graphite pneumoconiosis is stated. The lowest minimum is stated by Müller (47) – 5.5 years of exposure. Ranasinha & Uragoda (60) found that the average

Table 6. Epidemiologic studies of workers exposed to graphite.

Author	Type of workplace	Size of population	Investigation methods	Prevalence (cases per 100)
Hollmann (29)	Manufacture of carbon rods	33	Clinical examination, radiography	9
Kaestle (34)	Graphite mining and curing	120	Clinical examination, radiography	5
Bruusgaard (4)	Graphite mining and curing	83	Clinical examination	–
Dassanayake (7)	Graphite mining and curing	A. 50	Clinical examination, radiography	8
		B. 62	Clinical examination, radiography	?
Parmeggiani (54, 55)	Graphite mine, mill, electrode manufacture	415	Clinical examination, mass miniature radiography	6
Müller (45, 46, 47)	Graphite mill, crucible manufacture	A. 53	Clinical examination, radiography	28
		B. 71	Clinical examination, radiography	20
Brauss (3)	Graphite processing plant	60	Clinical examination?, radiography	13
Koelsch (35)	A. See Kaestle (34)			
	B. Graphite processing	550	Clinical examination, radiography	3
Zahorski (74)	Carbon electrode plant	52	Clinical examination, radiography	Period prevalence study?
Coscia et al (6)	Graphite mine	52	Clinical examination, radiography	73
Casalone & Rasetti (5)	Pipe manufacture	193	Clinical examination, radiography	5
Gaido et al (19)	Graphite mine [see also Coscia et al (6)]	50 + reference group	Clinical examination, radiography	72
Okutani et al (48)	Carbon electrode manufacture	256	Clinical examination, radiography or mass radiography?	44
Sklensky & Berka (67)	Graphite mine and drying station	57	Clinical examination, radiography	7
Koschnitsky et al (38)	Graphite mining and curing	188	Clinical examination, radioscopy, radiography in 33 suspected cases	8
Radionov et al (59)	Graphite mining and curing [see also Koschnitsky et al (38)]	188	No details given	4
Ranasinha & Uragoda (60)	Graphite mine	344 + reference group	70-mm mass radiography, clinical examination of those radiographically positive	23
Uragoda & Rajendra (71)	Graphite curing	125	Clinical examination, radiography	26
Zahorski et al (75)	Synthetic graphite electrodes	290	Clinical examination, radiography	Cohort study?
Hanoa (25)	Graphite mining and curing	105	Clinical examination, 100-x-100-mm mass radiography	1

number of years of exposure to develop radiographic abnormalities was 21.

Other reports on the effect of graphite dust

The case reports of graphite pneumoconiosis published in the 1940s served as a background for editorials in the *British Medical Journal* (77) and the *Lancet* (76). Heppleston (27) and Dunner (11) contributed to the discussion of the etiology of graphite pneumoconiosis in letters to the editor of the *Lancet*. McCord (43) published, in 1949, a review article about graphite as a source of dusty lung disease. No case was presented. Glauser & Rüttner (20) described graphite bodies in the lung tissue of a worker exposed to graphite

dust. The same topic was dealt with in another article by Rüttner (62). Schkavro (65) described a workplace with heavy graphite dust exposure in the Soviet Union. No case was reported.

Discussion

An essential issue in graphite pneumoconiosis research has been the question of etiology. Eight authors consider graphite alone, or above all other agents, as the cause of graphite pneumoconiosis. But only three, Brauss (3), Okutani et al (48), Lister (39)/Lister & Wimborne (40), suggest that pure or nearly pure graphite may cause graphite pneumoconiosis. In addition MacMahon (42), who expressed no definite opinion about the etiology, has presented a report which suggests that pure graphite may cause pneumoconiosis. Okutani et al, Lister & Wimborne, and MacMahon have presented cases with diagnoses supported by autopsy. These reports are suggestive although they do not specify the composition of *respirable* graphite dust in the workplace.

Parkes (53) summarized some reports of carbon pneumoconiosis where "quartz was either absent or of negligible amount – that is less than 1 per cent [p 191]." He mentioned the following five reports of graphite pneumoconiosis caused by "artificial or quartz-free graphite": Rüttner et al (63), Zahorski (74), Gaensler et al (18), Pendergrass et al (56, 57), and Town (68).

Do these five reports demonstrate what Parkes supposes them to? Rüttner et al (63) dealt with a case exposed to both graphite without quartz and carborundum dust. Zahorski (74) presented cases with exposure to synthetic graphite containing "very little" silica. Gaensler et al (18) presented cases involving virtual exposure to natural graphite with an unsatisfactorily specified content of free silica. Pendergrass et al (56, 57) presented cases with exposure to various, natural types of graphite dust; many involved exposure to other types of dust too. Town (68) dealt with a case of exposure to natural graphite with an unspecified content of free silica. I am afraid that out of these five reports only Zahorski's demonstrates the effect of "artificial or quartz-free graphite."

Parkes (53) referred to reports supposed to show that other types of pure or nearly pure carbon may cause pneumoconiosis; he referred to Gough's report (22) on coal trimmers working with washed clean coal, the reports of Miller & Ramsden (44) and Lister & Wimborne (40) on workers exposed to carbon black, and the reports of Otto & Einbrodt (51), Watson et al (73), and Foà et al (17) on workers exposed to carbon mixtures used in electrode manufacturing. In four of these reports traces of silica or quartz are mentioned (17, 22, 51, 73). In one report tuberculosis was mentioned as a partial cause of fibrosis (44). Only two reports presented any analysis of the dust in the workplace (17, 40).

In relation to the discussion of the etiology of graphite pneumoconiosis it is valuable if the diagnosis is supported by autopsy or lung biopsy during life. In only 39 of the reported 605 cases the diagnosis was based on or supported by autopsy or lung biopsy. Only 14 of these 39 cases were presented with relatively detailed documentation as to dust exposure [Engelmann (15), Harding & Oliver (26), Lister & Wimborne (40)]. Only one case suggests that nearly pure graphite may cause graphite pneumoconiosis (40).

Some experimental studies on animals have been done to illuminate the effect of graphite dust. Nine of the 11 studies dealt with the effect of graphite dust on lung tissue. When one considers all the experiments together, they do not leave much certainty as to the effect of graphite dust. The results suggest however that graphite dust containing free silica is fibrogenic in lung tissue. Still, the experiments have succeeded in bringing up many essential topics with regard to future experimental studies – eg, knowledge of the degree of graphite dust exposure needed to expect fibrogenic effects and information on the particle size distribution, the mandatory use of control groups of animals in the experiments and blind reading of the pathological findings, ie, the pathologist should not know whether the animals belong to the experimental or control group.

Further experimental studies must be done to clarify whether analytically pure graphite can cause pneumoconiosis in adequately exposed animals.

There are 18 epidemiologic studies of

workers exposed to graphite dust. Most of them are however invalid as epidemiologic studies because they do not comply with the ordinary requirements for study design. The prevalence rates of the studies vary greatly. The variation can probably be explained partly by differences in methodology and design and partly by real differences in prevalence rates. However, with two exceptions, the studies of employees in mines in Europe did not show a very wide prevalence range.

One might question whether mass miniature radiography provides the necessary validity in epidemiologic screening for pneumoconiosis. The answer might be no (53, 66, JA Dick, National Coal Board, personal communication). The ILO standards for equipment, film quality, and reading (31) give an opportunity to compare the results of different studies. Because so various standards were applied in the 18 studies, the results cannot be compared directly.

The epidemiologic studies demonstrate that graphite pneumoconiosis has been a relatively frequent chronic lung disease among certain groups of graphite-exposed workers. The disease is probably less frequent today. The epidemiologic studies have not been suitable to illuminate any association between the degree of exposure to graphite dust and the prevalence of pneumoconiosis. The studies do not provide the necessary information to relate the reported prevalence rates to the silica content in graphite dust in different workplaces. But most of the studies state that graphite pneumoconiosis develops only after many years of exposure. There is still a need for well-designed epidemiologic studies which could help to establish the dose-response relationship between graphite dust with different quartz contents and pneumoconiosis.

This literature review shows that there are a few reports which suggest that pure or nearly pure graphite may cause graphite pneumoconiosis. The reports presented do not provide overwhelming evidence. Several reports demonstrate, as expected, that graphite dust mixed with a certain content of free silica may cause pneumoconiosis – a mixed-dust pneumoconiosis. The present state of knowledge does not exclude the possibility that analytically pure graphite may cause pneumoconiosis. Free silica may not be necessary to develop graphite pneumoconiosis, but it may act as a modifier, promoting the development. The etiology and pathogenesis of graphite pneumoconiosis may be parallel to that of coal worker's pneumoconiosis.

Acknowledgment

Dr K Venables, TUC Centenary Institute of Occupational Health, London School of Hygiene and Tropical Medicine, has been my supervisor during my work with this review.

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Received for publication: 5 April 1983