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Advances in Brief

Crocidolite Asbestos Fibers in Smoke from Original Kent Cigarettes[1]

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Abstract

The original version of the Kent Micronite cigarette filter used crocidolite, a form of asbestos, from 1952 until at least mid-1956. Cigarettes from intact, unopened packs of the brand from this period were examined. One filter contained approximately 10 mg of crocidolite. Crocidolite structures were found in the mainstream smoke from the first two puffs of each cigarette smoked. At the observed rates of asbestos release, a person smoking a pack of these cigarettes each day would take in more than 131 million crocidolite structures longer than 5 μm in 1 year. These observations suggest that people who smoked the original version of this cigarette should be warned of their possible substantial exposure to crocidolite during the 1950s.

Introduction

The initial version of the filter in Kent cigarettes used crocidolite asbestos as the filtering agent (1). The filter consisted of rolled crepe paper interleaved with a loose mass of large diameter organic fibers that had been mixed mechanically with small diameter crocidolite fibers (Fig. 1; Refs. 2–5). There was no barrier or secondary filter between the end of this filter and the customer's mouth. This design was used from the introduction of the brand into test markets in March 1952 through at least May 1956 (6). In all, an estimated 11.7 billion cigarettes (585 million packs) were sold in the United States using this design (7) with advertising that emphasized the "health protection" supposedly provided by the filter (8).

The availability of unopened packs of original Kent cigarettes from cigarette pack collectors has permitted us to confirm the presence of crocidolite in the filters and to determine whether asbestos fibers entered the mainstream smoke from these cigarettes.

Materials and Methods

Cigarettes. Cigarettes from an unopened pack of Kent cigarettes with intact cellophane bearing a Pennsylvania tax stamp, dated by its federal tax stamp as having been made in 1955 or later, were used to confirm the presence of crocidolite, to measure the amount of asbestos in a single filter, to conduct a preliminary smoking experiment, and to examine the proximal filter end by scanning electron microscopy. The filters appeared undisturbed and in good condition. Cigarettes from an unopened pack of Kent cigarettes with intact cellophane bearing a Vermont state tax stamp, dated by its federal tax stamp as having been made in 1952, were used in the smoking experiments. These cigarettes were in excellent condition. There was no mold or discoloration, and the filters appeared intact and undisturbed.

Asbestos Content of the Filter by Weight. A filter was removed with a scalpel, weighed to 0.1 mg, and ashed in a muffle furnace at 450–500°C overnight. The weighed residue is reported as the mass of asbestos in the filter.

Preliminary Smoking Experiment. Four cigarettes were smoked on a standard, piston-type smoking machine at the American Health Foundation (Borgwaldt smoking machine RM 1/G, Hamburg, Germany; Ref. 9). The standard protocol was modified by the use of MCE[3] filters instead of Cambridge filters to trap smoke particles. Grids prepared for TEM from the MCE filters were contaminated heavily with glass fibers identical to those that comprise Cambridge filters. This contamination made it impossible to analyze these grids for crocidolite.

Smoking Apparatus (Smoker). Because of the contamination problem we encountered using the conventional smoking machine, a piston-type smoker was designed to smoke the cigarettes and collect smoke particles. The smoker consisted of a modified, new, 30-ml syringe (Becton Dickinson, Norcross, GA). The receiving end was bored out to 9 mm, and the intact syringe was washed out with xylene to remove the Dow 360 medical silicone lubricant. It was then relubricated with glycerol.

Treatments and Smoking. Cigarettes were humidified to a moisture content of 9 ± 1% (SD; Ref. 10). Two puffs were taken from each of nine cigarettes. Before insertion into the smoker, 3 of the cigarette filters were rolled (360° between the thumb and forefinger with 1–2 mm inward deflection) and 3 were pinched (once between thumb and forefinger with 1 mm inward deflection). The remaining three were not manipulated prior to insertion into the apparatus. Smoking was accomplished by inserting a cigarette into the receiving end of a syringe, sealing the cigarette at the syringe with commercially available silicone sealant, suspending the smoker assembly vertically, and lighting the cigarette with a butane lighter. After lighting, the plunger was pulled to 30 ± 1 ml within 1–2 seconds, and the cigarette was extinguished by capping with a preformed aluminum foil snuffer. The entire assembly was allowed to stand vertically for 90 min. For second puff experiments, the cigarette was transferred to a second syringe, sealed, relit, and smoked as already described. After standing, the cigarette and plunger were removed carefully.

Puff residue inside the smoker was prepared and examined as follows: the plunger was reinserted; the syringe assembly was filled with 20 ml of deionized distilled H_2O; capped with parafilm; hand shaken; and allowed to stand for 30 min. After standing, syringes were hand shaken, filled to 30 ml with deionized distilled H_2O, and the contents were pulled through a 13-mm 0.22-μm pore-size MCE filter. The MCE filter was then prepared for TEM analysis according to our laboratory's modification of the standard EPA protocol (11). Six control samples, 1991 Kent filter cigarettes, were smoked and analyzed in the same manner as 1950s cigarettes. Three blank samples consisting of laboratory air drawn through the smoking device, as well as six concurrent laboratory blanks, were also analyzed.

Microscopy of Filters and Smoke. To determine filter fiber types, fiber samples from the filter of a cigarette end were placed on a glass slide in refractive indices immersion liquid Series B 1.680 (Cargille Laboratories, Cedar Grove, NJ) and examined by polarizing light microscopy for morphology extinction, pleochroism, and sign of elongation.

To identify fiber types and fiber arrangement at the mouthpiece end of the cigarette filter, filters were removed from smoked and unsmoked cigarettes and examined with a Hitachi S-800 field emission scanning electron microscope. Fiber chemistry was determined with the use of a Tracor Northern TN 5500 EDXA system.

Puff residue was examined for asbestos structures content with the use of either a JEOL 1200 EX or Hitachi 7110 TEM at a magnification of ×20,000. Asbestos structures were identified positively by their morphology, by their chemistry with the use of a Tracor Northern TN 5500 or Kevex Delta Class 5

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[3] The abbreviations used are: MCE, mixed cellulose ester; TEM, transmission electron microscopy; EDXA, energy-dispersive X-ray analysis system.

Fig. 1. Mouthpiece end of an original Kent Micronite filter.

energy dispersive X-ray analysis system, and by their crystalline structure with the use of selected area electron diffraction. Asbestos structures were counted and classified according to standard EPA protocols (11).

Results

Fig. 1 shows the mouthpiece end of an original Kent cigarette Micronite filter. Fibers comprising the web between crepe paper layers were of two types, organic and inorganic. The inorganic fibers were confirmed by polarizing light microscopy to be crocidolite asbestos; a single filter contained 10 mg of crocidolite. On the basis of a fiber length of 5 μm, a diameter of 0.1 μm, and a density of 3.2 gm/cm^3, 1 filter could contain as much as 80 billion crocidolite asbestos fibers.

Under scanning electron microscopy, the organic fibers had the appearance of typical cellulose acetate. The dense fibers and fiber aggregates protruding from the mouthpiece of the filter seen with the use of scanning electron microscopy were confirmed to be crocidolite asbestos by EDXA (Figs. 2 and 3).

TEM analysis of puff residue showed that all cigarettes smoked released asbestos structures as fibers or fiber aggregates (clusters, bundles, or matrices of fibers) in both puffs (Fig. 4). These structures were identified positively as crocidolite by EDXA and selected area electron diffraction.

Data from the first and second puff experiments are shown in Table 1. Rolled cigarettes released from 64,410 to 156,600 total crocidolite structures in 2 puffs, and between 12,960 and 17,070 of these were 5 μm or longer. Pinched cigarettes released from 28,110 to 132,060 total crocidolite structures in 2 puffs, and between 4,950 and 6,330 of these were 5 μm or longer. Nonmanipulated cigarettes released from 76,200 to 728,520 total crocidolite structures in 2 puffs, and between 3,690 and 35,250 of these were 5 μm or longer. Overall, a mean of 170,240 crocidolite structures, including 18,020 structures 5 μm or more in length, were released in two puffs from a single cigarette. No

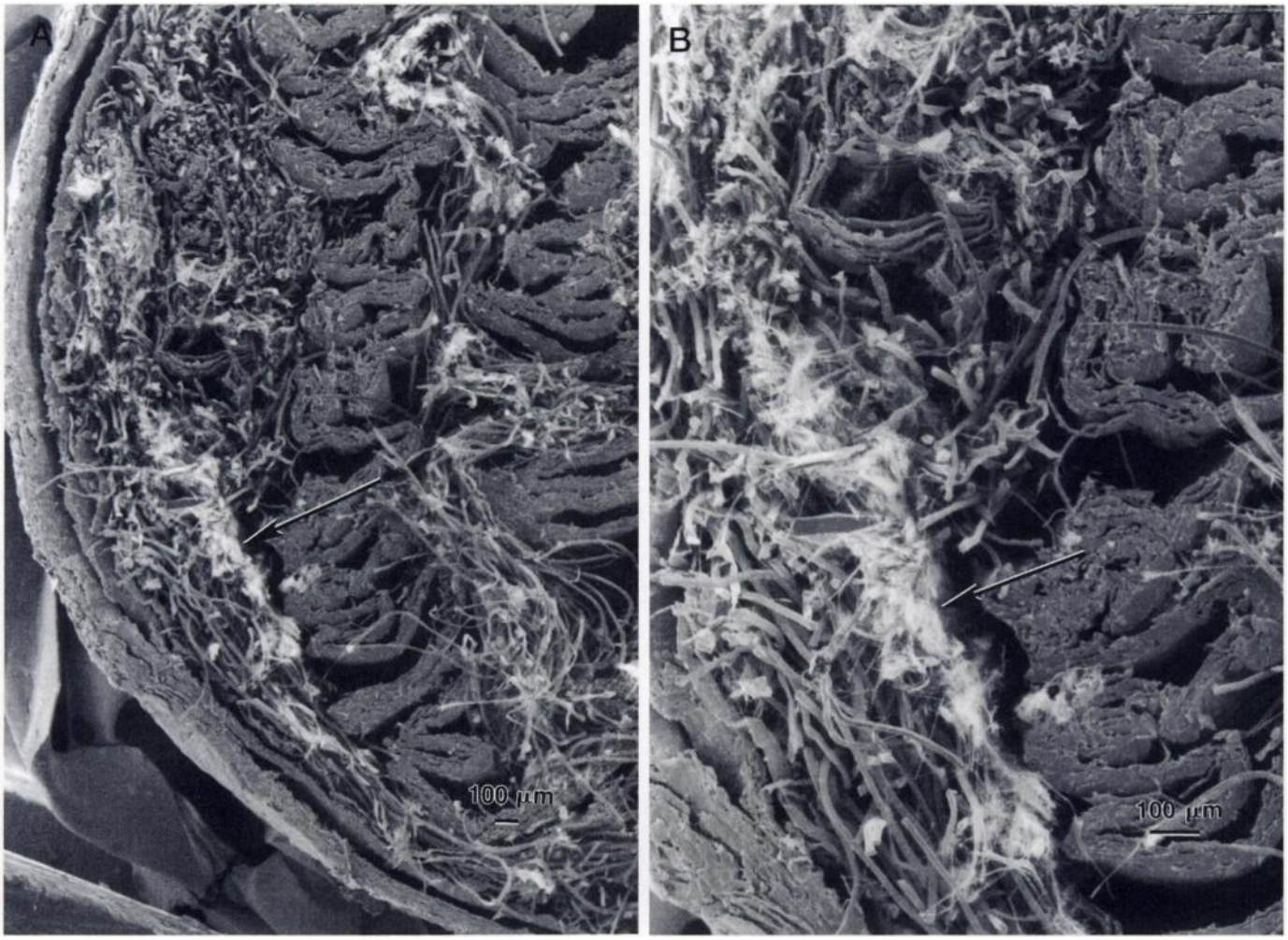

Fig. 2. Face view of mouthpiece end of filter. *Arrows*, crocidolite asbestos. *A* and *B*, scanning electron microscopy.

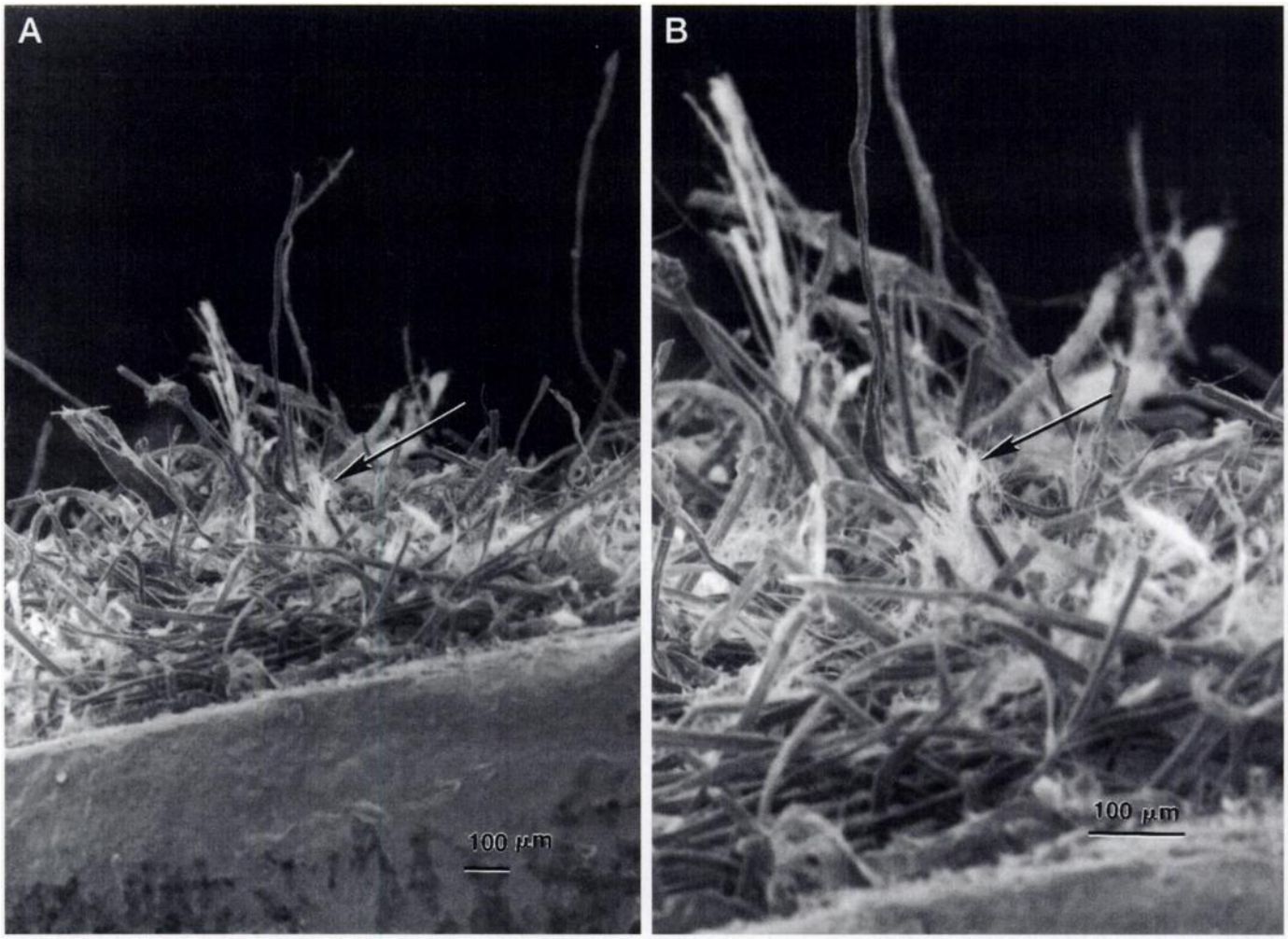

Fig. 3. Side view of mouthpiece end of filter. *Arrows*, crocidolite asbestos. *A* and *B*, scanning electron microscopy.

crocidolite structures were observed in any of the control or blank samples.

Discussion

Our data confirm the results of two series of TEM-based tests of Kent cigarette smoke performed in early 1954, one TEM series performed by Althea Revere (Life Extension Foundation), the other by Douglas Halgren and Dr. Ernest Fullam (Ernest Fullam Laboratories, Schenectady, New York). While both original reports have been lost, it is clear from other documentation that both laboratories observed asbestos structures in mainstream smoke from Kent cigarettes (12). These two studies were among the first to use electron microscopy to detect individual asbestos fibers. The present work extends these earlier studies by quantifying the amount of crocidolite released from the filter during the smoking process.

The number of structures observed in mainstream smoke in the present study is substantial. Extrapolating the observed average structure count to smoking 1 pack/day for 1 year, there would be 1.24 billion structures in the first 2 puffs of 7,300 cigarettes, and 132 million of these structures would be longer than 5 μm. Some authors have suggested that asbestos structures longer than 5 μm have a greater carcinogenic potential than do structures less than 5 μm (13).

Although a large number of fibers entered the smoke stream, only a small fraction of the total amount of crocidolite in the filter was released. We estimate that the average number of structures observed in the first two puffs represents less than 0.001% of the crocidolite in a single original Micronite filter.

While asbestos was found in smoke from each cigarette, there was substantial cigarette to cigarette variability in the amount released. Rolling or pinching the filters prior to smoking did not seem to influence the results. The observed variability may be a consequence of the design and manufacturing process of the filter itself. Crocidolite was mixed mechanically with textile fibers, and this mixture was then

Table 1 *Asbestos structures per puff (30 ml)*

	PUFF 1		PUFF 2		BOTH PUFFS	
Cigarette	Total structures	Structures >5 μm	Total structures	Structures >5 μm	Total structures	Structures >5 μm
Rolled, smoked						
1	37,860	2,280	118,740	10,680	156,600	12,960
2	62,430	13,740	1,980	1,320	64,410	15,060
3	89,700	16,140	23,250	930	112,950	17,070
Pinched, smoked						
4	27,570	6,330	540	0	28,110	6,330
5	114,600	17,190	17,460	1,740	132,060	18,930
6	14,130	2,250	29,970	2,700	44,100	4,950
Nonmanipulated smoked						
7	112,860	16,920	76,350	18,330	189,210	35,250
8	459,840	18,390	268,680	29,550	728,520	47,940
9	11,760	480	64,440	3,210	76,200	3,690
Mean	103,417	10,413	66,823	7,607	170,240	18,020

Fig. 4. Crocidolite asbestos in mainstream smoke from an original Kent cigarette. TEM; ×3000.

layered onto a paper backing. Several such layers of fibers and paper were then twisted and rolled into a filter (2–5). This mechanical process would have resulted in crocidolite fibers in each filter being distributed unevenly at the proximal end. In some cases, the disposition of fibers would have favored a large release, while in others, the geometry would have permitted less to enter the mainstream smoke. Our scanning electron microscopy observations confirm the plausibility of this explanation (Figs. 2 and 3).

Our data probably underestimate the amount of crocidolite released in an actual smoking situation for 3 reasons: (*a*) these tests examined only smoke from the first 2 puffs, and there was still substantial release of asbestos during the second puff; (*b*) the numbers given, in conformance with EPA counting rules (11), reflect "structures" and not "fibers." Overall, 18.7% of the structures observed were aggregates rather than individual fibers. An aggregate includes at least 3 and often hundreds of fibers; and (*c*) the structures recovered from the smoking apparatus are only those that had settled on the interior of the syringe and had become suspended in the wash water. Structures that remained adherent to the wall were not counted.

Of all the forms of asbestos, crocidolite is implicated most strongly as causing mesothelioma (14–16), and the risk of mesothelioma in exposed populations reaches its peak 35 to 40 years after exposure (13). An epidemic of asbestosis, lung cancer, and mesothelioma has occurred among workers at the factory where the filters for the original Kent cigarette were made (17).

Recently, Pauly *et al.* (18) have shown that 12 popular brands of cigarettes shed filter material into the smoke stream and that those fibers are deposited into the lungs during the smoking experience. On the basis of results from the present study and the study of Pauly *et al.* (18), in conjunction with the earlier work by Revere, Fullam, and Halgren (12), we conclude that the original Kent cigarettes tested at our laboratory accurately represent how the cigarettes would have released crocidolite fibers if tested in the same manner in the early 1950s. This in turn strongly suggests that there is an increased risk of mesothelioma among people who smoked these cigarettes during that time point.

While the original version of Kent was on the market, the brand had an overall market share of 0.72% (7). Its best year was 1954, when it accounted for 1.1% of the market. In that year, about 550,000 packs were sold each day. Thus, up to several hundred thousand people still alive were exposed to substantial amounts of crocidolite from smoking this cigarette.

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