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Dermatological Findings in Capacitor Manufacturing Workers Exposed to Dielectric Fluids Containing Polychlorinated Biphenyls (PCBs)

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ABSTRACT. Significant occupational exposure to polychlorinated biphenyls (PCBs) may occur in the manufacturing of capacitors and transformers, in which PCBs are used as electrical insulators. Reports of adverse health effects resulting from PCB exposure have come primarily from an incident resulting from the accidental ingestion of contaminated rice oil in Japan in 1968 ("Yusho"). Dermatological findings were prominent features and included pigmentation disturbances and chloracne. To evaluate the dermatological effects of long-term occupational exposure to PCBs, a cross-sectional clinical survey was conducted of 326 capacitor manufacturing workers. A high prevalence (37%) of dermatological abnormalities was found, but typical PCB-associated signs, such as chloracne, were less frequent than among patients with "Yusho," despite high concentrations of plasma PCB. An association between dermatological signs and plasma levels of higher homologues of PCBs was suggested, but contaminants which have been reported to be present in commercial PCB mixtures (polychlorinated dibenzofurans) should be considered an etiologic factor or co-factor in the development of "PCB-associated" dermatological findings.

OCCUPATIONALLY INDUCED dermatological disease may occur with a great variety of clinical and pathological manifestations. Some may be nonspecific and, in the absence of known occupational exposure history, are not immediately recognized as occupationally related on clinical grounds alone.[1]

With the continuous introduction of new industrial compounds, previously well-known clinical entities of occupational skin disease may become more complicated, especially in exposure situations which involve more than one toxic agent. Furthermore, the skin may not be the only organ system affected by such agent(s), requiring evaluation of other organ systems to establish the correct etiological diagnosis.

Halogenated hydrocarbons. This group of chemicals has wide industrial applications, and is known to affect various organ systems of the body; they may be associated with hepatic, neurological, endocrinological, and immunological dysfunction.[2] Halogenated hydrocarbons, and the chlorinated hydrocarbons in particular, also seem to have a predilection for the pilosebaceous apparatus of the skin.[3-5] Acne has been described after exposure to hydrocarbons such as chlorinated naphthalenes,[6] chlorinated dibenzofurans,[7,8] and contaminants of chlorophenols.[9,10]

Polychlorinated biphenyls. The polychlorinated biphenyls (PCBs) are a class of chlorinated aromatic compounds. They are prepared by the chlorination of biphenyl with anhydrous chlorine and iron filings or ferric chloride as catalyst. The resulting product is a complicated mixture

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of chlorobiphenyls with different degrees of chlorination and many substitutional isomers.[11] Most commercial mixtures are mobile oils.

Polychlorinated biphenyls are manufactured in the United States under the trade name Aroclor. All Aroclors are characterized by a four-digit number representing the type of molecule and degree of chlorination; toxic effects in animals treated with Aroclors have been studied extensively.[12-14]

Because of their stability and chemical inertness, Aroclors have many industrial applications. Their excellent dielectric properties have rendered the PCBs very useful as electrical insulators of capacitors and transformers.

Reports of adverse health effects in humans resulting from PCB exposure have come primarily from an incident involving the accidental ingestion of contaminated rice oil in Japan in 1968,[15,16] resulting in the epidemic of the disease called "Yusho" (Japanese: "oil disease"). Dermatological findings were prominent features[16,17] and included enlargement and elevation of the follicular orifices; acne; and dark-brown pigmentation of the skin, nails, conjunctivae, and oral mucosa. In typical cases, hypersecretion of the Meibomian glands, swelling of the upper eyelid, and irregular lid margins were also noted. The acne lesions were described as chloracne.

An incident similar to the one reported in Japan occurred recently in Taiwan, and initial reports describe severe dermatological abnormalities consistent with exposure to PCBs and related polychlorinated hydrocarbons.[37] The clinical and pathological manifestations of abnormalities observed among the affected subjects in Taiwan have become known as Yu-cheng (Chinese: "oil diseases") and are quite similar to those associated with Yusho.

One of the earliest reports in the United States of cutaneous eruptions after inhalation of chlorobiphenyls was provided by Schwartz in 1942.[18] There have subsequently been other reports describing cutaneous abnormalities including chloracne in populations occupationally exposed to PCBs.[19,20] However, compounds such as chlorophenols have also been found to contain chloracegenic substances, and the report by Kimmig and Schultz[10] of chloracne among workers in chlorophenol factories provided evidence that the contaminant tetrachlorodibenzo-*p*-dioxin (TCDD) was the active agent causing the skin lesions. The importance of the biological activity of this and related compounds will be discussed elsewhere in this paper.

Table 1.—Age Distribution of 289 Capacitor Manufacturing Workers

Age (yr)	Males		Females	
	Number	Percent	Number	Percent
< 30	31	20	14	10
30-39	38	25	19	14
40-49	42	28	31	23
50-59	25	16	55	40
60+	17	11	17	13
Total	153	100	136	100

MATERIALS AND METHODS

A clinical field survey of 326 capacitor manufacturing workers was conducted to investigate the health effects associated with long-term occupational exposure to PCBs. Over the years, various mixtures of PCBs (e.g., Aroclor 1254 and 1242) had been used at this facility. For 5 yr prior to this study, Aroclor 1016 and, to a minor degree, Aroclor 1221 had been used exclusively in the capacitor manufacturing process. The workers were exposed to the PCB-containing dielectric fluids along the production line where the electrical equipment was filled with PCBs. Air PCB levels varied throughout the plant and there was no uniform exposure among the workers. In areas with the lowest exposures mean air levels were 0.007 mg/m^3, while in departments where more direct contact with the fluid was required, such as testing of the equipment or quality control, mean levels of 0.41 mg/m^3 were recorded.

In departments where capacitors were immersed in the dielectric fluid air level ranged from 0.9 mg/m^3 to 11.0 mg/m^3.

The exposure resulted mainly from inhalation of PCB vapors released from the fluid, but there was also potential for skin contact and ingestion. The examination included a wide spectrum of both clinical and laboratory tests, a summary of which has been reported elsewhere.[21]

General medical and dermatological examinations included review of symptoms potentially related to PCB exposure. The dermatological symptoms, recorded on a specially designed questionnaire, included history of rashes, burning sensation of the skin, the occurrence of acne after starting work in the plant, pigmentation disturbances, and discoloration and/or deformation of the nails.

Plasma PCB levels were measured by gas chromatography (electron capture detection) according to methods previously described.[38] Polychlorinated biphenyl residues were calculated as Aroclor 1248 (for peaks with retention times less than *p,p'*-DDE) hereafter designated as lower homologs of PCBs (LPCB). Peaks with retention times greater than p,p'-DDE were calculated as Aroclor 1254, hereafter called higher homologs of PCBs (HPCB).

Differences in plasma PCB concentrations were analyzed by Student *t* test and by non-parametric tests, i.e., Wilcoxon's Rank Test and Smirnoff's Maximum Deviation. Since plasma PCB levels were available for 289 individuals, this report will confine itself to the dermatological findings of the population.

Population. The age distribution of the examined workers, 153 males and 136 females, is shown in Table 1. Their duration of employment can be summarized as follows: 32 individuals (11%) had been employed less than 5 yr, 58 (20%) had been employed between 5 and 10 yr, while 112 (39%) workers had been employed for 20 yr or more. All workers were white.

RESULTS

Sixty-nine (45%) of the male workers and 75 (55%) of the female workers had a history of dermatological complaints. The various dermatological symptoms were classi-

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Table 2.—Dermatological Symptoms Reported by 289 Capacitor Manufacturing Workers

Symptoms	Males			Females		
	Total*	No. with Symptoms	Percent	Total*	No. with Symptoms	Percent
Rash	151	52	34	131	62	47
Burning	151	40	26	131	34	26
Acne	148	17	11	130	15	12
Thickening	147	5	3	128	6	5
Darkening	149	2	1	131	5	4
Discoloration of fingernails	129	1	1	129	5	4

*Missing data account for the differences in the total number.

Table 3.—Dermatological Abnormalities Among 289 Capacitor Manufacturing Workers

Dermatological Symptom	Males (N = 153)		Females (N = 136)	
	Number with Condition	Percent with Condition	Number with Condition	Percent with Condition
Erythema	24	16	17	13
Swelling	5	3	2	1
Dryness	23	15	14	10
Thickening	14	9	16	12
Rash	9	6	6	4
Hyperpigmentation	16	10	13	10
Comedones	6	4	4	3
Acne	7	5	9	7

fied in several categories (Table 2). Skin rash was reported by 114 (40%) to have occurred after initiation of work in the plant; a history of acne (adolescence acne excluded) was reported by 32 individuals (12%). The prevalence of reported pigmentation disturbances, thickening of the skin and discoloration of the nails, was lower (Table 2).

A history of other dermatological diseases was given by 23 individuals and included 11 with allergic excema (other than due to PCB-containing oil); two with psoriasis; two cases with lichen planus; and eight with histories of pigmented nevus (operated), tinea verruca, vitiligo, neurodermatitis, lipoma, pityriasis rosea, and Bowen's disease. Physical examination revealed that 59 male workers (39%) and 48 female workers (35%) had abnormal dermatological findings.

The various skin abnormalities observed on physical examination are shown in Table 3. Acneform eruptions (Fig. 1a–1c) were observed in 16 individuals (6%), 7 male and 9 female workers. All but 2 (females) were above 30 yr of age, and 8 were 50 yr or older.

Conjunctival and palpebral abnormalities were found on physical examination of 46 workers (16%). Redness of the conjunctiva, palpebral hyperpigmentation and edema (Fig. 2) were observed among 48 workers (17%). Such dermatological findings often occurred in combination. Five workers (2%) had abnormal secretions from the eyes, while 3 (1%) had typical enlargement of the Meibomian glands.

In addition to these findings, physical examination revealed the following 17 cases with other dermatological diseases, i.e., 4 cases with allergic excema, 2 with psoriasis, verruca, neurodermatitis, and tinea, respectively, and single cases with seborrheic dermatitis, lichen planus, vitiligo, tinea, and Bowen's disease.

To investigate the association between skin abnormalities and plasma PCB levels, as well as different PCB homologs, a subgroup of 42 individuals (22 males and 20 females) with skin abnormalities which clinically were thought to be related to PCB exposure in particular (i.e., hyperpigmentation, hyperkeratosis, comedones, and chloracne) was identified.

A significant difference (P = .03) was found between the mean concentrations of the higher homologs of PCBs (HPCB) for the male workers using a Student t test adjusting for unequal variances; the workers with skin abnormalities had higher mean HPCB levels (Table 4). Because the distribution of HPCB was skewed, a t test was also used to compare the mean log (HPCB). The result, although not statistically significant, was suggestive of a difference (P = .07). No statistically significant differences were observed when the HPCB distributions were compared

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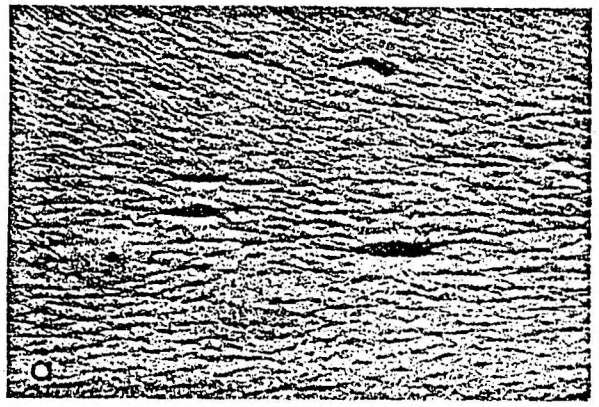

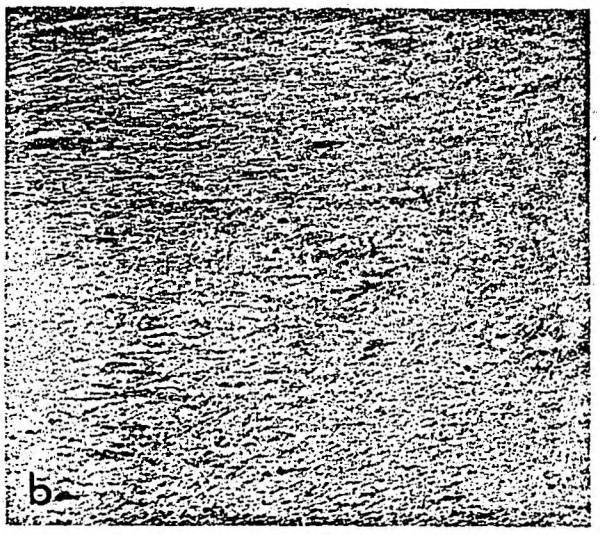



Fig. 1a and b. Comedos, papulo-postules (acneform) and depressed scars on the back of a 50-yr-old capacitor manufacturing worker. The lesions began to appear after exposure to PCB-containing dielectric fluid.

Fig. 1c. Malar region of 32-yr-old PCB-exposed worker showing comedos and acneform lesions. Note periorbital hyperpigmentation.

using non-parametric tests. No statistically significant differences were found in the analysis of LPCB within the male workers. For the females, no statistically significant differences were found in either mean HPCB or LPCB levels between those with and without skin abnormalities (Table 4).

Furthermore, the association between dermatological abnormalities and biochemical parameters, potentially related to manifestations of PCB toxicity, was investigated.

The levels of the following biochemical parameters were examined: bilirubin, serum glutamic-oxaloacetic transaminase, serum glutamic-pyruvic transaminase, alkaline phosphatases, γ-guanosine 5'-triphosphate, lactate dehydrogenase, total lipids as well as cholesterol.

Both parametric (t tests) and non-parametric statistical methods were applied; no significant association was found between any of the biochemical tests and dermatological abnormalities.

DISCUSSION

The prevalence of abnormal dermatological findings on physical examination in approximately 37% of the group and half of the population had dermatological symptoms. Although a wide spectrum of skin abnormalities was noted, some have been shown to be associated with exposure to halogenated hydrocarbons and to PCBs in particular.[3, 16]

Dark-brown pigmentation disturbances, which were found in various parts of the body in 10% of the examined workers, are rather specific findings in PCB-related disease; however, the prevalence of these changes was much lower than that observed among the Yusho patients in the first detailed report of 138 individuals.[16]

One of the most characteristic dermatological responses resulting from exposure to halogenated aromatic hydrocarbons is chloracne. It was likewise a prominent finding among the Yusho patients, with a prevalence of 82%. All of the patients with Yu-cheng had one or more dermatological signs of poisoning. Chloracne develops primarily in areas where there is active secretion of sebum, but may also occur frequently in other than the classical sites, such as the head, ears, abdomen, and thighs. The nose is typically not affected. Open comedones are very characteristic.

In the present study 16 of the examined workers (6%) were found to have acne, in most cases associated with several typical comedones; no attempt was made, however, to further characterize the observed lesions histopathologically.

The mean duration of employment for those with acne

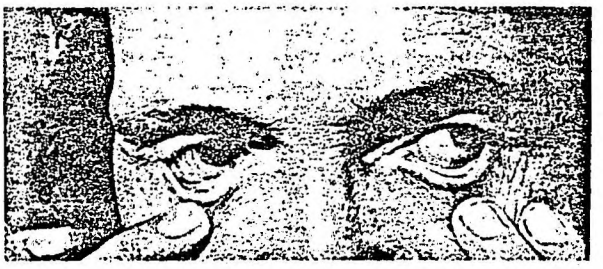

Fig. 2. Thickened inferior palpebrae and periorbital hyperpigmentation in a 40-yr-old female PCB-exposed worker.

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Table 4.—Means and Standard Deviations of Plasma PCB Levels (ppb) in 289 Capacitor Manufacturing Workers

Variable	Sex	Number	Skin Status	Mean	Standard Deviation	P*
HPCB	M	22	Abnormal	96.77	137.45	.03
HPCB	M	131	Normal	50.49	79.79	
HPCB	F	20	Abnormal	56.25	102.38	NS
HPCB	F	116	Normal	33.36	54.98	
LPCB	M	22	Abnormal	226.73	350.73	NS
LPCB	M	131	Normal	137.89	267.12	
LPCB	F	20	Abnormal	114.35	117.42	NS
LPCB	F	116	Normal	106.47	183.47	

*P Value obtained from Student *t* test.

was not significantly different from those with normal skin.

The age distribution naturally excluded adolescent acne.[22] While there is a remarkable paucity of information in the literature regarding the age at which spontaneous regression of adolescent acne occurs, persistence of lesions beyond the early twenties is rare.

Ocular findings were also observed in this study group, with palpebral hyperpigmentation and edema being hallmarks of PCB effects.

Of interest was the suggestion of a relationship between dermatological signs and plasma concentration of higher homologs of PCBs.

The male workers with the more specific PCB-related dermatological abnormalities showed a tendency towards higher HPCB levels.

Several aspects of PCB-associated dermatological disease might well be subjects for future investigation. For instance, there is the unresolved question of whether it is the dermal absorption of PCBs per se which is the principal cause of the dermatological manifestations or whether the skin may serve as an excretory route for PCBs and/or metabolites, whether the findings are the result of metabolic activities,[12] or combinations of such factors. There are recent experimental data demonstrating that other organ systems may have an "excretory" function.[13] The skin, with such concepts, would be an important diagnostic site for the evaluation of PCB-associated systemic disease. Most currently available diagnostic methods are both nonspecific and insensitive, and may, in fact, provide less information than clinical examination of the skin.

The biological effect of polychlorinated dibenzofurans, which have been reported to be present in commercial PCB mistures including the rice oil associated with Yusho,[23-26] should also be considered a possible etiologic factor or co-factor.[39]

These contaminants, possibly generated during processing (heating) of the oil, constitute a mixture of different positional isomers.[27,28] Investigations on specimens of liver and mesenteric adipose tissue of patients with fatal outcome of Yusho have shown that certain isomers tend to persist in these tissues and may be responsible for some of the toxic effects of the ingested, PCB-containing rice oil.[29,30]

As referred to above, the polychlorinated dibenzodioxins and the highly toxic compound 2, 3, 7, 8-tetrachlorodibenzo-*p*-dioxin in particular are frequent contaminants of chlorophenols and have also been associated with toxic manifestations in various organ systems. Chloracne, however, is a prominent feature of the clinical syndrome, which also may include porphyrinuria,[31] disorders of plasma lipids,[32] and neurological changes.[33] A recent industrial accident in a plant in Seveso, Italy scattered tetrachlorodibenzo-*p*-dioxin over several communities; although no final scientific evaluation of this incident has been published to date, several cases of chloracne, particularly among children, have occurred.[34]

Recently, concern over the use of the herbicide 2, 4, 5-T, a phenoxyacetic acid containing 2, 3, 7, 8-tetrachlorodibenzo-*p*-dioxin as contaminant, has been raised in the United States, since it is estimated that some 106 million pounds of 2, 4, 5-T (Agent Orange) were used as defoliant in Vietnam from 1962 to 1971,[35,36] and that a considerable number among the military personnel and the indigenous population have been exposed.

Epidemiologic studies on the long-term dermatological effects of PCBs may provide much needed information about the significance of different routes of entry. Experimental studies are warranted to clarify pathogenesis and mechanisms of action.

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