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Occupational Health Hazards among Double Sided Printed Circuit Board Manufacturers

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AES, AS, SH and NAM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AS, SH and NAM designed the patient files and managed the literature searches. Authors AS, NAM and SH managed the analyses of the study, wrote the discussion and recommendations of this study. Author AES revised the discussion and recommendations. All authors read and approved the final manuscript.

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ABSTRACT

Workers in printed circuit boards (PrCBs) industry have a long history of occupational exposures to toxic substances, however little is known about the long-term health consequences of such exposure.
Aims: To determine the prevalence of some health problems among manufacturers of printed circuit boards and to formulate recommendations for occupational safety and health at this factory. Subjects and Methods: A case-control study was conducted in the first double sided printed circuit board manufacturing factory in Egypt, during the period from December 2012 to January 2013. Fifty three workers engaged in the process of printed circuit board manufacture were matched with sixty six referent subjects from the administrative department. All workers were personally interviewed filling a special questionnaire involving occupational history and full clinical examination. Investigations as Lead, Cadmium, serum copper and zinc levels were measured.
Results: Eighten exposed workers (34%), had occupational asthma; 7 (13.2%) had contact dermatitis; 8 (15.1%) had ocular manifestations versus 11 (16.7%); 1 (1.5%); 4 (6.1%); 1 (1.5%) respectively for the control group. Blood levels of lead (48.84±10.0

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versus. 13.60±4.70, p<0.001), cadmium (35.09±14.0 versus 23.90±5.70, p<0.001), and copper (1.32±0.64 versus 0.94±0.33, p<0.001), were statistically significantly higher among the exposed group than controls, while zinc levels (40.75±19.34 versus 77.31±15.21, p<0.001) were statistically significantly lower among the exposed group than controls. Blood levels of lead (r=. 543; p<. 001) and copper (r=. 463; p<. 001) were found to be positively correlated with the duration of employment.

Conclusion: PrCBs manufacturing has been implicated with many health problems. **Recommendations:** Proper safety measures should be enforced in the workplace. Pre-employment and periodic medical examination should be done for exposed workers. Further studies are recommended for PrCBs workers.

Key words: Printed circuit boards; Heavy metals-Occupational asthma; Contact dermatitis; Health Hazards.

1. INTRODUCTION

Printed circuit boards (PrCBs) are essential components of electronic equipments. They are also called printed wiring boards. PrCBs development has revolutionized the electronics industry. In recent years, the average rate of world-wide PrCBs manufacture is increased. They can be used to mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces. They are involved in the manufacturing of business machines, computers, as well as communication, control and home entertainment equipment [1]. They essentially re-placed electrical wiring with a landscape of conductive paths on a rigid surface. PrCBs consisted of patterns of conductive material formed onto a non-conductive base. The conductor is generally copper, although aluminum, chrome, nickel and other metals have been used. The metal is fixed to the base through the use of adhesives, pressure, heat bonding, and sometimes screws. Those materials and metals along with electronic parts are attached to the board by a solder containing lead and tin [2]. Although developments in such semi-conductor components as memory chips and microprocessors gain the public attention, PrCBs have quietly evolved to meet the needs of those components, including changes in their size, density, weight, and strength and power requirements [3]. PrCBs manufacturing entails many potential health and safety hazards. These hazards can be classified into three broad categories: chemical, physical and psychosoical. Chemical hazards are including organic solvents (such as formaldehyde, dimethylformamide, ethylene glycol monomethyl ether and methoxyacetic acid), acids, bases and metal fumes; physical hazards include covering electric shock, noise, vibration, high temperature operation fire and explosion [4]. PrCBs workers are exposed to a variety of chemicals quiet similar to those of other microelectronics workers, however little is known about the outcome of such exposures. In Egypt, health hazards among workers in electronic industry, were not thoroughly studied. This is the first health survey conducted in a factory that is a pioneer in the PrCBs industry in Egypt. This study was designed to assess health implication of PrCBs process on exposed workers. To execute this task, we designed our objectives as follow: To determine the prevalence of some health problems among manufacturers of printed circuit boards. To measure some of heavy metals encountered in this industry. To propose recommendations for occupational safety and health in this industry.

2. SUBJECTS AND METHODS

2.1 Study Population

The study was carried out in the first factory for manufacturing printed circuit boards in Giza, Egypt during the period from December 2012 to January 2013. This study was conducted on two groups: an exposed and a control group. The total working force was 122 male workers, constituting the whole workforce of the factory. The exposed group consisted of 56 male workers occupationally exposed to the printed circuit board process. The control group included 66 male workers in administrative departments of the company, who have never been occupationally involved in PrCBs manufacturing. The control group was matched to the exposed group as regards age, sex, socioeconomic status and smoking habit. Upon their request, three of the exposed workers refused to take part in this study. The remaining 53 workers were involved in printed circuit boards (PrCBs) manufacturing, double sided board, for more than one year, working in 12 hours based shift. The process is accomplished by producing patterns of conductive material on a non- conductive substrate by subtractive or additive process (the conductor is usually copper, the base can be pressed epoxy, Teflon, or glass). The steps of manufacturing the board are cleaning, surface preparation of the base, electrolysis, copper plating, map or pattern printing, masking, electroplating and etching. The study protocol was first approved by the Occupational and Environmental department ethical committee, Kasr Al Ainy Hospital, Faculty of Medicine, Cairo University. Prior to this study, a written consent to participate in the study and an approval to give blood samples were obtained. During the study, the ethical guidelines of good clinical practices (GCPs) and strict confidentiality were observed throughout sample collection, coding, testing, and recording of the results.

2.2 Methods

The studied groups were subjected to a specially designed detailed questionnaire including: socio-demographic data including age, residence, marital status, and special habits, present, past and family history. Occupational history included: current job and its nature, previous jobs, duration of employment in years; Health complaints: onset, duration and relation to work; Clinical examination: comprehensive general examination including the chest, skin and ocular examination. Blood samples were collected for measuring a complete blood picture, kidney functions (urea, creatinine) and blood levels of lead, cadmium, copper and zinc. All heavy metals were detected using the atomic absorption spectrophotometry. Ventilatory function assessment was conducted for all workers included in this study using calibrated electronic spirometer.

2.3 Statistical Analysis

Data obtained from the study were coded and entered using the statistical package SPSS version 16. The mean values, standard deviation (SD) and ranges were then estimated for quantitative variables, as for the qualitative variables, the frequency distribution was calculated. Comparisons between exposed and control groups were done using the independent simple t-test. The correlations between individual variables were calculated using Pearson correlation coefficient. P values less than 0.05 were considered statistically significant.

3. RESULTS

The exposed group consisted of 53 workers all were men their mean age was 39.20±4.8 years ranging from 30 to 53 years. Mean duration of exposure was 13.71±3.0 years, ranging from 5 to 20 years. The mean age of the control group was 39.18±5.8 years, ranging from 32 to 52 years, showing no statistically significant difference between the exposed group and the controls. Systolic and diastolic blood pressure was statistically significantly elevated among PrCBs workers compared to the control subjects, but both groups showed levels within normal range. Other sociodemographic characteristics of printed circuit board workers and control group are shown in Table 1.

Table 1. Sociodemographic characteristics of printed circuit board workers and control group

General Characteristics	PrCB Workers n=53	Control n=66	*Statistical tests*	*P* value
Age (yrs) (Mean±SD)	39.20±4.8	39.18±5.8	.026*	.979
Duration of work (yrs.) (Mean±SD)	13.71±3.0	-------	-------	-------
Blood pressure (Mean±SD)				
SBP	124.94±14.0	106.52±21.7	5.361*	< .001
DBP	79.60±10.0	73.40±9.1	3.486*	.001
Smoking habit				
Smokers n**(%)**	19(64.2)	30(45.5)		
Nonsmokers n (%)	34 (35.8)	36(54.5)	2.202* *	.138
Marital status				
Married n**(%)**	7(88.7)	57(86.4)	.143* *	.705
Unmarried n (%)	6(11.3)	9(13.6)		

** Independent simple t-test value; significantly (2 tailed) p<0.001*
*** Pearson Chi-Square*

History of typical asthma was found among 18 exposed subjects (34%) Table 2, however, only 13 (24.5%) showed obstructive manifestations by ventilatory function test results. Restrictive pulmonary impairment was detected in 8 exposed workers (15.1%) and combined restrictive and obstructive among 5 cases (9.5 %) Table 3. History of contact dermatitis that resolved by being away from exposure was found among 7 subjects (13.2 %), only one case showed residual skin manifestations that didn't improve by removal from exposure and needed medical intervention. History of conjunctivitis and upper respiratory tract irritation were found in 8 cases (15.1%) and ophthalmic examination showed chronic conjunctivitis in 4 cases (6.1%). All encountered health complaints had exposure-response relationships that were emphasized by a detailed history taking Table 2.

The mean values of the complete blood picture and kidney function tests among printed circuit boards' workers and control group were shown in Table 4.

The mean levels of lead, cadmium and copper among PrCBs workers showed statistically significantly higher values compared to that in the control as presented in Table 5.

Table 2. Frequency distribution of clinical manifestations among PrCB Workers and control group

Clinical manifestations	PrCB Workers n=53	Control n=66	X^2*	*P* value
Occupational asthma	18(34)	11(16.7)	4.765	.029
Contact Dermatitis	7(13.2)	1(1.5)	6.907	.009
Conjunctivitis	8(15.1)	4(6.1)	2.649	.104
Upper respiratory tract irritation1	8(15.1)	1(1.5)	7.753	<.001

** Fisher's exact chi-square*

Table 3. Results of ventilatory function test between printed circuit boards workers and control group

Ventilatory function impairment	PrCB Workers (n=53) n(%)	Control (n=66) n(%)	X^2*	*P* value
Obstructive	13(24.5)	3(4.5)	10.086	.001
Restrictive	8(15.1)	1(1.5)	7.753	.005
Combined	5(9.5)	1(1.5)	3.850	.050

** Fisher's exact chi-square*

Table 4. Complete blood picture and kidney functions tests among printed circuit board workers and control group

	PrCB Workers (n=53)	Control (n=66)	*t-test* *	P value
RBCs	4.34±0.63	4.30±0.60	.466	.642
WBCS	6.79±1.29	7.08±1.46	-1.015	.312
Hb gm/dl	13.71±0.67	13.50±0.71	1.615	.109
Urea	18.33±3.7	18.04±2.69	.500	.618
Creatinine	1.04±0.32	0.99±0.21	.875	.383

** Independent simple t-test value; significantly (2 tailed) p<0.001*

Table 5. Blood levels of measured heavy metals and trace elements among printed circuit board workers and control group

	PrCB Workers (n=53)	Control (n=66)	*t-test**	*P* value
Lead Ug/dL	48.84±10.0	13.60±4.70	3.909	<0.001
Copper(serum) Ug/dL	35.09±14.0	23.90±5.70	5.926	<0.001
Cadmium Ug/dL	1.32±0.64	0.94±0.33	4.455	<0.001
Zinc (serum) Ug/dL	40.75±19.34	77.31±15.21	-11.54	<0.001

** Independent simple t-test value; significantly (2 tailed) p<0.001*

Serum zinc levels showed lower values among PrCBs workers compared with the controls. The correlation between different variables revealed a positive significant correlation between duration of employment in PrCBs and both lead and copper (r= 0.543, p<0.001; r=0.0463, p<0.001 respectively). There were negative correlations between duration of employment in PrCBs and each of hemoglobin; urea and creatine level Table 6.

Table 6. Correlation coefficient between duration of employment and different investigations among printed circuit board exposed workers

	r	*P* value
SBP*	.325	.018
DBP**	.208	.135
Lead	.543	< .001
Cadmium	.137	.328
Copper	.463	< .001
Zinc	-.080	.570
Hb	-.230	.097
Urea	-.335	.014
Creatinine	-.088	.531

** SBP: Systolic blood pressure., ** DBP: Diastolic blood pressure*

4. DISCUSSION

The manufacture and use of electrical and electronic products have increased dramatically over the past several decades. One of the major health concerns in the PrCBs manufacture process is exposure to the fumes generated during soldering and electronics assembly. Respiratory irritants encountered during these processes contributed to the high prevalence of occupational asthma among exposed workers as shown in Table 1. Some of these irritants are heavy metals, machining fluids, lubricants, solvents, paints and coatings, adhesives, soldering fluxes and other various chemicals. The fumes generated from the fluxes used in solders and liquid fluxes used in dip soldering are known respiratory sensitizers that are liable to cause occupational asthma, rhinitis and conjunctivitis. La dou, [4], similarly concluded the presence of high doses of heavy metals in the electronics products industry. Several studies have reported that the inhalation of metal dust and fumes is associated with adverse health effects such as metal fume fever and other respiratory diseases [5,6]. Adding to the hazardous material exposure, poor industrial hygiene and long work shift in confined poorly ventilated workplace may aggravate work related health complaints. Most of PrCBs, require soldering mask. The solder mask application is found in the surface finish. The manufactures use cluster, sets of chemicals processes and technologies that can substitute for one another to perform a specific function. In the current study, smoking habit didn't contribute to the higher prevalence of ventilatory function test impairment among exposed compared with the controls, no statistically significant difference as regards smoking habits between both groups was found Table 1. Asthma is characterized by the presence of reversible airflow obstruction; however, irreversible airflow obstruction develops in some patients [7]. In our study, ventilatory function testing demonstrated statistically significantly higher impairment among PrCBs workers compared with the control subjects (p<0.001). Diagnosis of occupational asthma due to exposure to fumes generated from soldering flux during manufacturing PrCBs, was evident among 13 workers based on pulmonary function test, however 18 cases gave a typical history of asthma among exposed workers versus 11 control subjects. In our country patients are treated mostly by clinical history, sign and symptoms and their lung function test are rarely assessed. This study provides evidence that exposure to fumes and dust encountered during the process of printed circuit board manufacture, increases the risk of respiratory complaints. The present findings were with the perception that asthma is a chronic inflammatory disease in which ongoing tissue injury and repair result in irreversible fibrotic changes in the airways leading to decline in lung functions. Skin irritation and sensitization among workers in the electronics industry are associated with a variety of physical, chemical and psychosocial causes. Causal agents for skin diseases in electronics workers were studied by many researchers and include epoxy resins, acrylates, solvents, metals, fiberglass and flux [4,8-10]. In the current study, we found that 7 workers (13.2%) had hand contact dermatitis and none had allergic dermatitis, Table 2. Our results agreed with Shiao et al. [11], who conducted a field investigation to determine the prevalence, patterns and risk factors of occupational hand dermatitis among electronics workers. The survey was conducted in five electronics plants using a self-administered questionnaire on skin symptoms and risk factors. Skin examination and patch test were followed for those with symptoms compatible with hand dermatitis. A total of 3070 workers completed the questionnaire. Among them, 302 (9.8%) reported to have symptoms (itching with either redness/scaling) compatible with contact dermatitis on hands.

Recently, Szoboszlai et al. [12], investigated the elemental composition and mass size distribution of indoor aerosol particles in a working environment where soldering of PrCBs took place. They reported that, based on the elemental ratios, correlations, size distribution data and single particle analysis e.g. soldering, fluxing, etching and cleaning. The concentration of particulate matter (PM) and the elemental components increased at the wave solders. The main constituents of the leaded and the unleaded melt were recognized in the indoor aerosols. In the case of PM10, the Pb levels in the workplace were approximately 3.8 times higher on average than the outer Pb levels. Flux-related and etching-related elemental compositions were also identified at work place. This is in resemblance to the results of our study, that found higher blood levels of heavy metals as lead and cadmium, among exposed workers, Table 5. Lead is the most widely used in electronic devices for various purposes, especially during soldering, resulting in a variety of health hazards attribute to environmental contamination. The advantages of lead include low melting point, freedom from whiskers, in susceptibility to tin – pest, slowing down on the inter metallic phase formation or copper dissolution, technical reliability and cost-effectiveness [13-15]. Huo et al. [16], found that primitive electronic-waste recycling activities contribute to the elevated blood lead levels in children living in Guiyu in China. Recently, Yang et al. [17], investigated the association between Pb and Cd exposure, physical growth, bone and calcium metabolism in children of an electronic waste (e-waste) processing area in Guiyu, China. They found the mean values of blood lead levels (BLLs) 7.30 µg/dl and blood cadmium levels (BCLs) 0.69 µg/L. They concluded that primitive e-waste recycling can threaten the health of children with elevated BLLs and BCLs that may eventually cause adult osteoporosis. Similarly, our results revealed high BLLs (48.84±10.0 µg/dl) and BCLs (1.32±0.64 µg/dl), and statistically positive correlation between duration of employment and their blood lead levels Table 6.

Cadmium and zinc are similar in structure and function in the human body. Cadmium displaces zinc in some of its important enzymatic and organ functions; thus, it interferes with these functions. In the current study, we found higher levels of cadmium among exposed workers compared with the controls. Regarding what we have mentioned above, we have found in our study that serum levels of zinc are lower than those of the controls, this because of the competitive action of divalent cations between zinc and cadmium.

Other metals used in PrCBs, rather than lead, are copper, aluminum, tin, iron, nickel, zinc, gold and silver. Among them, copper is the primary metal enriched in the four size fractions that is between 0.15 and 1.25 mm [18]. This can be explained by exposure to copper during the process of plating. In the current study we found high serum levels of copper among exposed workers Table 5 and statistically significant positive correlation between its levels and duration of employment as demonstrated in the Table 6. This can be explained by exposure to copper during the process of plating, etching or soldering. Serum zinc levels showed lower values among our workers relative to that among the controls. This is supported by the results of Soleo et al. [19], who studied health risk assessment of exposure to metals in workers of steel foundry. They found that Zn showed significantly higher urinary concentrations in controls than in the exposed subjects. This could be explained by the competitive action of divalent cations. Ayinde et al. [20], mentioned that occupational and environmental exposures to lead remain a public health problem as lead alters physiological processes by inducing oxidative stress and mimicking divalent cations. On the other hand, Kasperczyk et al. [21], evaluated the effect of occupational lead exposure on blood concentrations of zinc. They found that zinc level was unchanged in the exposed group compared with the control group.

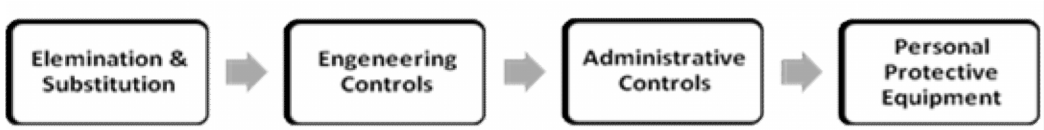
LaDou, [4], presented the wide range of occupational, environmental health and regulations controlling this industry. He also stated that, PrCBs industry had received remarkably little regulatory and enforcement attention in the United States and elsewhere. Szoboszlai et al. [12], concluded that, although the concentrations of Pb were less than the limit value of the OSHA and WHO, there was a maximum in the fine mode and the mass size distributions of Pb and other metals that increase the risk of adverse effects among exposed workers in PrCBs. In 2003, the European Union (EU) [22] enacted the Restriction on Hazardous Substances (ROHS) Directive that bans the use of lead, mercury, cadmium, hexavalent chromium, and certain brominated flame retardants (BFRs) in most electronics products sold in the EU market beginning July 1, 2006. However, in Egypt we still broadly use these toxic metals and chemicals in PrCBs industry. It is understood that, the electronics industry provides valuable jobs, nonetheless, attention is needed to identify greener and safer alternatives and controls.

One of the limitations of this study, is we can't assume a cause effect relationship between exposure to heavy metals during manufacturing of PrCBs and the health effects found in our study. Because little is known about the long-term health consequences of exposure to chemicals by semiconductor workers; nothing is known of long-term exposure to low levels of these chemicals and also nothing is known about long-term exposure to low levels of combinations of chemicals and reaction products. Despite documented evidence of adverse health effects of electronic industries from the World Health Organization (WHO), the International Labor Organization (ILO), various government agencies and individual scientists, no uniform set of protective standards for workers in the electronics sector is found.

5. CONCLUSION AND RECOMMENDATION

We can conclude that the fumes emitted during the industrial process pose a health hazard. There is considerable exposure to heavy metals and solvents during the process of manufacturing printed circuit boards, especially during electrolysis, etching, drilling and electroplating. So, proper safety measures should be insured during the industrial process. Hierarchy of Hazard control of the workplace should be applied to protect the workers from health hazards associated with this industry as shown in a flow chart below.

Hierarchy of Hazard Control



Substitution and even elimination of these hazardous substances at sources of heavy metals and solvent exposure during, electrolysis, etching, drilling and electroplating are important. Proper engineering measures to reduce the effect of the fumes as enclosed systems and proper maintenance of machinery together with proper and effective ventilation at work place are necessary. Good and proper ventilation is a must at work place. The fumes must be given appropriate extraction and cleaning before being discharged to the atmosphere. Further down the hierarchy is to apply administrative controls providing specialist training or putting a supervisor in place to monitor the work environment. A last resort control, is personal protective equipment such as safety goggles and glasses will minimize the risk but not address the hazards. Pre-employment and periodic medical examination for exposed workers, for early detection of health affection are needed. One year follow up by measuring blood levels of lead, cadmium and copper are also recommended. The magnitude of this problem has to be studied on a large scale to support our findings.

COMPETING INTERESTS

There is no conflict of interest in this research.

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